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ABSTRACT

This six-volume student text is designed for use by Air Force personnel enrolled in a self-study extension course for avionics instrument systems specialists. Covered in the individual volumes are career field familiarization (career field progression and training, security, occupational safety and health, and career field reference material); specialty administration and aircraft familiarization (supply; maintenance data collection, reporting, and management; supervision; and aircraft familiarization, hardware, and tools); electronic principles (fundamentals of electronics, alternating and direct current circuits, generators and motors, inductance and capacitance, electron tubes, semiconductors devices, analog computers, and binary systems and logic circuit elements); maintenance fundamentals and engine instruments (direct reading pressure gauges, synchros and variable reluctance systems, thrust measurement systems, tachometers and temperature-indicating systems, and vertical scale engine instrument systems); liquid quantity, utility, and recording systems; and flight and navigation instruments (basic pilot-static, electronic pilot-static, and navigation systems; vertical scale flight instruments, angle-of-attack/stall warning and sextants; and instrument systems test equipment). Each volume in the set contains a series of lessons, exercises at the end of each lesson, a bibliography, and answers to the exercises. Volume review exercises and change supplements are included. (MN)

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AVIONICS INSTRUMENT SYSTEMS SPECIALIST

(AFSC 32551)

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ITEM	TYPE	DESIGNATION OR TITLE	INVENTORY CONTROL NUMBER	VRE ANSWER SHEET IDENTIFICATION
			140	
3	VOL	VOL 1, Career Field Familiarization	32551 01 8202	
4	VRE	VOLUME REVIEW EXERCISE (VOL 1)	32551 01 23	32551 01 23
5	VOL	VOL 2, Specialty Administration and Aircraft Familiarization	32551 02 8207	
6	VRE	VOLUME REVIEW EXERCISE (VOL 2)	32551 02 24	32551 02 24
7	VOL	VOL 3, Electronic Principles	32551 03 8201	
8	SUPP	CHANGE SUPPLEMENT (VOL 3)	32551 03 S01 8410	
9	VRE	VOLUME REVIEW EXERCISE (VOL 3)	32551 03 24	32551 03 24
10	VOL	VOL 4, Maintenance Fundamentals and Engine Instruments	32551 04 8206	
11	SUPP	CHANGE SUPPLEMENT (VOL 4)	32551 04 S01 8303	
12	VRE	VOLUME REVIEW EXERCISE (VOL 4)	32551 04 23	32551 04 23
13	VOL	VOL 5, Liquid Quantity, Utility, and Recording Systems	32551 05 8204	
14	VRE	VOLUME REVIEW EXERCISE (VOL 5)	32551 05 22	32551 05 22
15	VOL	VOL 6, Flight and Navigation Instruments	32551 06 8204	
16	VRE	VOLUME REVIEW EXERCISE (VOL 6)	32551 06 21	32551 06 21
17	SUPP	CHANGE SUPPLEMENT (VOLs 2, 4 and 6)	32551 00 S01 8402	
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LIST OF CHANGES

COURSE NUMBER 32551	CAREER FIELDS, POLICIES, PROCEDURES AND EQUIPMENT CHANGE. ALSO, ERRORS OCCASIONALLY GET INTO PRINT. THE FOLLOWING ITEMS UPDATE AND CORRECT YOUR COURSE MATERIALS. PLEASE MAKE THE INDICATED CHANGES.
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1. CHANGES FOR THE TEXT: VOLUME 1

a. Page iii, Preface, lines 13-14: Delete ", and then study . . . a separate inclosure." Lines 2-3 fr bot: Change "27 hours (9 points)" to "21 hours (7 points)" and delete "These hours and . . . with Chapter 1."

b. Page 6: Delete page in its entirety.

c. Page 67, col 1, line 7: Delete "See Module 10009 for answers to objectives 004-046."

2. CHANGES FOR THE TEXT: VOLUME 2

a. Page 81, col 1, lines 1-2: Change "25 workdays" to "30 calendar days." Line 8: Change "20 workdays" to "20 calendar days."

b. Page 169, col 2, line 15: Change "24 workdays" to "20 calendar days." Lines 16-17: Change "20 workdays" to "20 calendar days." Lines 17: Change "25 workdays" to "30 calendar days."

3. CHANGES FOR THE TEXT: VOLUME 4

a. Page 49, Exercises (632)-3: Change "calibrations" to "calibration" and "tester" to "transmitter."

b. Page 110, answer 632-3: Change "Percentage deflection" to "The master."

4. CHANGE FOR THE TEXT: VOLUME 6

Page 128, col 1, line 2 fr bot: Change "33K-100" to "33K-1-100." Line 8 fr bot: Change "33K1-100" to "33K-1-100."

5. CHANGES FOR THE VOLUME REVIEW EXERCISE: VOLUME 1

a. Page 14, line 1: Change "pg," to "81."

b. Page 17, question 106: In the stem of the question, after "The" add "primary."

c. The following questions are no longer scored and need not be answered: 6-60 inclusive, 113 and 121.

6. CHANGE FOR THE VOLUME REVIEW EXERCISE: VOLUME 2

Question 2 is no longer scored and need not be answered.

7. CHANGE FOR THE VOLUME REVIEW EXERCISE: VOLUME 3

Question 121 is no longer scored and need not be answered.

LIST OF CHANGES

COURSE NUMBER 32551	CAREER FIELDS, POLICIES, PROCEDURES AND EQUIPMENT CHANGE. ALSO, ERRORS OCCASIONALLY GET INTO PRINT. THE FOLLOWING ITEMS UPDATE AND CORRECT YOUR COURSE MATERIALS. PLEASE MAKE THE INDICATED CHANGES.
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8. CHANGE FOR THE VOLUME REVIEW EXERCISE: VOLUME 4

The following questions are no longer scored and need not be answered: 30, 76 and 121.

9. CHANGES FOR THE VOLUME REVIEW EXERCISE: VOLUME 5

a. Page 7, question 59: In the stem of the question, change "+1 at N" to "+1 at W."

b. The following questions are no longer scored and need not be answered: 16 and 92.

10. CHANGE FOR THE VOLUME REVIEW EXERCISE: VOLUME 6

The following questions are no longer scored and need not be answered: 34, 48, 52, 122, 123 and 124.

32551 01 8202

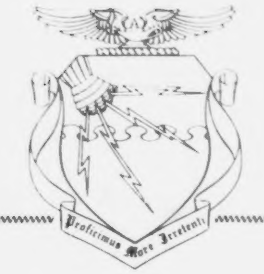
CDC 32551

AVIONICS INSTRUMENT SYSTEMS SPECIALIST

(AFSC 32551)

Volume 1

Career Field Familiarization


Proficimus More Irretenti

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3360 TECHNICAL TRAINING GROUP (ATC)
CHANUTE AIR FORCE BASE, ILLINOIS

EXTENSION COURSE INSTITUTE, GUNTER AIR FORCE STATION, ALABAMA

Preface

THIS COURSE provides you with the knowledge required to upgrade to the 5 or 7 skill levels in the 325X1, Avionics Instrument Systems Career Field. As the self-study portion of your on-the-job training program, it deals with job-related areas.

These six volumes are the sole source for the Specialty Knowledge Test subjects.

Promotion Fitness Examination subjects are covered only to the extent indicated in the Specialty Training Standard as required for upgrading to the 5 skill level.

Volumes 1, 2, and 3 cover general subjects such as safety, technical orders, maintenance management, data collection, hand tools, and electronic principles, respectively. Volume 4 covers engine instrumentation from simple direct pressure gages and tachometers to complex flow and thrust measurement and vertical scale systems. Volume 5 deals with means of measuring liquid quantity, position indicating systems, and flight data recording systems. Volume 6 explains airspeed, altitude, and other flight and navigation systems.

You should study career field progression in Chapter 1 of this volume, and then study the revised Module 10009, referenced in the text. Module 10009 covers on-the-job training and is included as a separate inclosure. Next comes Chapter 2 dealing with aspects of security; Chapter 3 covers occupational safety and health, and Chapter 4 explains Air Force technical orders and the technical order system.

Code numbers appearing on figures are for preparing agency identification only, and should be of no concern to the student.

Direct your questions or comments relating to the accuracy or currency of this volume to the course author: 3360 TCHTG/TTGU-F, ATTN: MSgt Lawrence B. Miller, Chanute AFB IL 61868. If you need an immediate response, call the author, AUTOVON 862-2041, between 0730 and 1600, Central Standard Time, Monday through Friday. *(NOTE: Do not use the suggestion program to submit changes or corrections for this course.)*

If you have questions on course enrollment or administration, or on any of ECI's instructional aids (Your Key to a Successful Course, Behavioral Objective Exercises, Volume Review Exercise, and Course Examination), consult your education officer, training officer, or NCO, as appropriate. If this person can't answer your questions, send them to ECI, Gunter AFS AL 36118, preferably on ECI Form 17, Student Request for Assistance.

This volume is valued at 27 hours (9 points). These hours and points include those assigned to the module that you will study in conjunction with Chapter 1.

Material in this volume is technically accurate, adequate, and current as of April 1981.

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Answers for Exercises 67

NOTE: In this volume, the subject matter is developed by a series of student-centered objectives. Each of these carries a three-digit number and is in boldface type. Each sets a learning goal for you. The text that follows the objective gives you the information you need to reach that goal. The exercises following the information give you a check on your achievement. When you complete them, see if your answers match those in the back of this volume. If your response to an exercise is incorrect, review the objective and its text.

Career Field Progression and Training

YOU ARE a member of one of the largest organizations in the world today—the United States Air Force. You have every reason to be proud of the Air Force and the job you do.

As an avionics instrument systems specialist or technician, just what is your job? Actually, your job will vary according to the unit to which you are assigned; but, as different as your individual duties may be, the general job requirements remain the same.

Your job title, "Avionics Instrument," is an overall job description. Let's examine each part of it. The word, avionics, is a combination of the two words, aviation and electronics. It is defined as the electrical and electronic devices used in aviation. The word, "instrument" is defined as a measuring device for determining the present value of a quantity under observation. It is also defined as an electrical or mechanical device used in navigating an airplane. These two words provide a good identification of the equipment you maintain. From their definitions, you may conclude that your job covers a broad range of equipment and duties.

This course will identify much of the job-related equipment and duties you will encounter throughout your Air Force career. For general military knowledge, you must study AFP 50-34, *Military Training Standard Promotion Fitness Exam Study Pamphlet.*

1-1. Description of the Career Ladder

Each Air Force Specialty Code (AFSC) has its own meaning. In order for you to understand what each portion of your AFSC means, we have broken it out in parts, so that you can better understand what each digit means. We will discuss what the digits identify in the Avionics Systems Career Field to help you learn how to interpret the digits in your AFSC.

001. Interpret the digits in your AFSC, and identify the different levels in the AFS.

Your Air Force Specialty Code. Review your own AFSC, 32551, for example. The first two digits identify the Avionics Systems Career Field, which includes bombing, navigation, radio, and radar systems, as well as instruments and auto pilot. The third AFSC digit identifies the career field subdivision or career ladder. In this case, the 5(325) refers to auto pilot/instrument subdivision on the career field chart.

The fourth digit identifies your skill level. AFSC 32531 is the code of an apprentice, 32551 is the code of a specialist, and 32571 is the code of a technician. The 9 skill level identifies a superintendent, who directs the activities in this career field subdivision. Your branch chief probably holds AFSC 32591.

The fifth digit of an AFSC identifies the specific Air Force specialty within the subdivision. In your subdivision, "automatic flight control" or "auto pilot" is 0, and "avionics instrument" is 1.

Career field. When you entered the Air Force, you were assigned AFSC 99000 (bottom block of fig. 1-1). This means that you were a "basic" who had not yet been assigned to a career field. At that time you were given an Airman Qualification Examination (AQE). The AQE tested you in four areas known to be important to success in certain Air Force schools: (1) mechanical, (2) administration, (3) general, and (4) electronics. On the basis of these scores and your interviews with personnel placement officials, you were placed in this career field. Your background, your desires, and the Air Force needs were considered in assigning your career field.

At this point, you were sent to a basic avionics instrument systems course. In some career fields, airmen are sent directly to the field on directed-duty assignment (DDA), but not in your Air Force Specialty (AFS). The basic avionics instrument systems course, 3ABR32531, is required for progression in your career field. The airmen on DDA learn the fundamentals by on-the-job training. To attain their 3 skill level, they must perform to their shop supervisor's satisfaction, and also meet the requirements of AFR 35-1, *Military Personnel Classification Policy (Officers, Warrant Officers, Airmen).*

Refer again to the lower blocks of figure 1-1. Note that, as a "basic," you could not advance in rank. But, as a career field helper, 32X10, you could reach E-2. When you attained your 3 skill level (32531), you could be promoted to E-3 and E-4. You could not become eligible for E-5 until after you obtained your 5 skill level, as

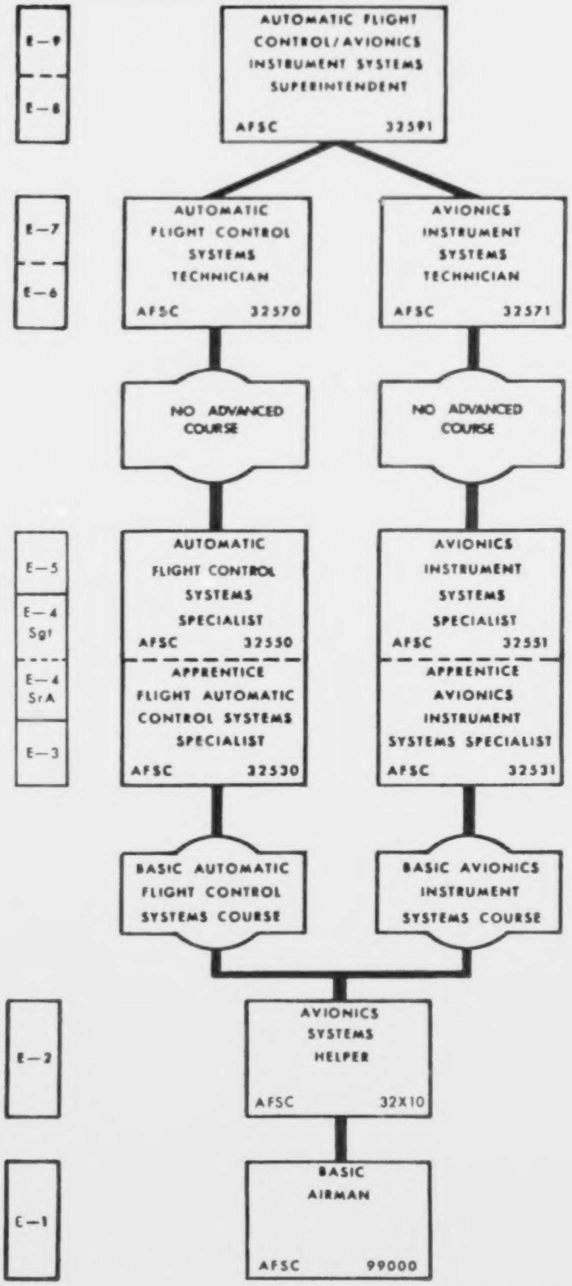

E—9
E—8
AUTOMATIC FLIGHT CONTROL/AVIONICS INSTRUMENT SYSTEMS SUPERINTENDENT
AFSC 32591
E—7
E—6
AUTOMATIC FLIGHT CONTROL SYSTEMS TECHNICIAN
AFSC 32570
AVIONICS INSTRUMENT SYSTEMS TECHNICIAN
AFSC 32571
NO ADVANCED COURSE
NO ADVANCED COURSE
E—5
E—4 Sgt
E—4 SrA
E—3
AUTOMATIC FLIGHT CONTROL SYSTEMS SPECIALIST
AFSC 32550
APPRENTICE FLIGHT AUTOMATIC CONTROL SYSTEMS SPECIALIST
AFSC 32530
AVIONICS INSTRUMENT SYSTEMS SPECIALIST
AFSC 32551
APPRENTICE AVIONICS INSTRUMENT SYSTEMS SPECIALIST
AFSC 32531
BASIC AUTOMATIC FLIGHT CONTROL SYSTEMS COURSE
BASIC AVIONICS INSTRUMENT SYSTEMS COURSE
E—2
AVIONICS SYSTEMS HELPER
AFSC 32X10
E—1
BASIC AIRMAN
AFSC 99000

Figure 1-1. 325XX Career Ladder Chart.

shown in the center block of figure 1-1. After you accomplish your on-the-job training and are awarded the 7 skill level, you will become eligible for promotion to E-6 and E-7.

Exercises (001):

1. The first two digits of AFSC 32551 indicate ________ ________ ________ ________.

2. The third digit of AFSC 32551 indicates ________ ________ ________ ________ ________.

3. The fourth digit of AFSC 32551 indicates ________ ________.

4. The fifth digit of AFSC 32551 indicates ________ ________ ________ ________.

5. Give the title and AFSC of a new recruit.

6. What is the route for progression from a career field helper to an apprentice avionic instrument system specialist position?

7. An avionics instrument system specialist holds what AFSC?

8. A superintendent is identified by what skill level?

9. Give the title of a 32571.

10. How does an airman on directed duty assignment earn his or her 3 level?

11. How do airmen in the 325XX career fields reach the 3 level?

12. When can you become eligible for promotion to E-5?

1-2. AFSC Progression

Your main interest at this time is probably centered on the question, "How do I progress up the career field ladder?" Actually, you have already started. You have completed the basic avionics instrument systems course and were awarded a 32531 AFSC upon completion. You are now in upgrade training for AFSC 32551. What does it take to get there?

002. Identify the requirements for progression to each skill level of the AFSC 325X1 career ladder, and list the different types of the AFSC.

Skill Upgrading. The most important factor at this time is increasing your skill level. That is why you are studying this CDC. When you have completed all the volumes of this course, you will be given the Course Examination (CE). When you have passed the CE, you have one of the big hurdles out of the way toward being awarded your 5 skill level; but, there is more to it than passing the CE. Passing the CE indicates that you have the broad job knowledges required for upgrading to the 5 skill level AFSC. In addition, you must have demonstrated some proficiency on the job as an avionics instrument systems specialist. This is done in two ways: first, you must have performed for at least 6 months at the 5 skill level, and second, you must be recommended by your supervisor for award of the 5-skill level AFSC.

To be awarded a 7 level, you must perform the duties of a 7 level for a minimum of 1 year, complete the required supervisory training, and be recommended by your supervisor. In all cases, you must meet the mandatory requirements or their equivalents to be awarded the AFSC. These are listed in the specialty description. When you have met all the requirements, then you are eligible to be awarded AFSC 32551 or 32571, as applicable. You must be a 32551 to be promoted from sergeant (E-4) to staff sergeant (E-5). In addition, your assignments while you are in the Air Force are based on your AFSC. This makes it necessary to explain that there are several kinds of AFSCs.

Types of AFSCs. First, there is the awarded AFSC; this is an authorized AFSC which has been awarded to individuals following certification of their abilities to perform the duties of an AFS at a specified skill level. This is the AFSC that we have been talking about in the preceding paragraphs. You also have a primary AFSC; this is the awarded AFSC in which you are most highly qualified to perform duty. Unless you have worked in some other AFSC and cross-trained into avionics instrument systems, your awarded AFSC and your primary AFSC will be the same. You also have a control AFSC. This is the AFSC that controls your assignments and assists the Air Force in identifying and controlling training requirements. It is normally the same as your primary AFSC. Last, there is the duty AFSC. This is an AFSC that identifies the skill level of the position to which you are assigned on your organization's manning requirements. You are probably assigned to a position that authorizes a 32551 AFSC, even though you have only a 3-level AFSC; therefore your duty AFSC is probably 32551.

Skill-Level Responsibilities. Most of the responsibilities at the 5 skill level are related to actually working on avionics instrument components and systems; therefore, all of the requirements for obtaining a 5 level deal with systems knowledge and job proficiency. The main difference between the 3-skill-level airman and the 5-skill-level airman is not so much what they do, but in how skilled they are, and how closely they must be supervised while doing their jobs.

The 7-skill-level technicians should be the best troubleshooters and most highly skilled individuals in the shop. Their experience on different aircraft and systems gives them a background that enables them to cope with the most difficult maintenance problems. A 7-level technician is probably the key figure in your upgrade training program and may even be your shop chief. The duties of a 7-level technician involve the management of materials, supplies, and people; therefore, some management and supervisory training is mandatory before you can earn a 7 skill level.

The 9-skill-level superintendent primarily manages such resources as money and people and normally oversees two or more shops. These duties make extensive management training mandatory.

Exercises (002):

1. Why are you studying this CDC?

2. List the areas you must improve in before you can be upgraded from the 3 to 5 level or from the 5 to 7 level.

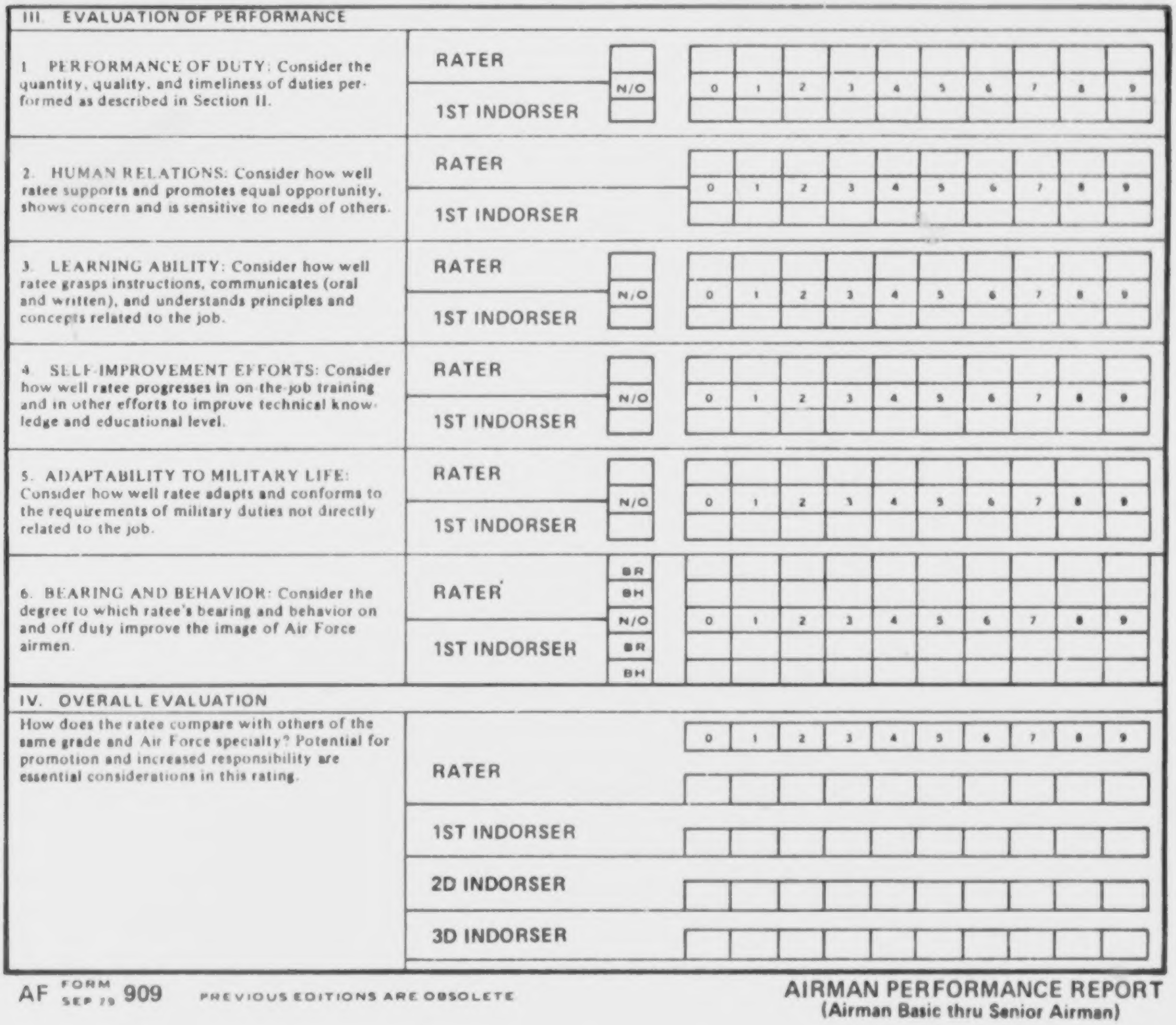
3. Where are the mandatory requirements for award of the AFSC listed?

4. List the types of AFSCs in your specialty and the purpose of each.

5. Which of the items in the following list are requirements for progression from the 3- to 5-skill-level AFSC?
   a. Complete a formal basic course.
   b. Have at least 6 months' experience at the 5 skill level of the AFSC.
   c. Successfully complete the CDC.
   d. Have 6 months' experience in the 3-level AFSC.
   e. Meet mandatory requirements or equivalents.
   f. Be recommended by your supervisor.
   g. Have 1-years' experience in the 5-level AFSC.
   h. Have 6 months' time in grade.

6. What kind of AFSC was used in assigning you to your current AF base?

7. Which two types of AFSCs are normally the same?



III. EVALUATION OF PERFORMANCE			
1. PERFORMANCE OF DUTY: Consider the quantity, quality, and timeliness of duties performed as described in Section II.	RATER	☐	☐☐☐☐☐☐☐☐☐☐
		N/O	0 1 2 3 4 5 6 7 8 9
	1ST INDORSER	☐	☐☐☐☐☐☐☐☐☐☐
2. HUMAN RELATIONS: Consider how well ratee supports and promotes equal opportunity, shows concern and is sensitive to needs of others.	RATER		☐☐☐☐☐☐☐☐☐☐
			0 1 2 3 4 5 6 7 8 9
	1ST INDORSER		☐☐☐☐☐☐☐☐☐☐
3. LEARNING ABILITY: Consider how well ratee grasps instructions, communicates (oral and written), and understands principles and concepts related to the job.	RATER	☐	☐☐☐☐☐☐☐☐☐☐
		N/O	0 1 2 3 4 5 6 7 8 9
	1ST INDORSER	☐	☐☐☐☐☐☐☐☐☐☐
4. SELF-IMPROVEMENT EFFORTS: Consider how well ratee progresses in on-the-job training and in other efforts to improve technical knowledge and educational level.	RATER	☐	☐☐☐☐☐☐☐☐☐☐
		N/O	0 1 2 3 4 5 6 7 8 9
	1ST INDORSER	☐	☐☐☐☐☐☐☐☐☐☐
5. ADAPTABILITY TO MILITARY LIFE: Consider how well ratee adapts and conforms to the requirements of military duties not directly related to the job.	RATER	☐	☐☐☐☐☐☐☐☐☐☐
		N/O	0 1 2 3 4 5 6 7 8 9
	1ST INDORSER	☐	☐☐☐☐☐☐☐☐☐☐
6. BEARING AND BEHAVIOR: Consider the degree to which ratee's bearing and behavior on and off duty improve the image of Air Force airmen.	RATER	BR	☐☐☐☐☐☐☐☐☐☐
		BH	☐☐☐☐☐☐☐☐☐☐
		N/O	0 1 2 3 4 5 6 7 8 9
	1ST INDORSER	BR	☐☐☐☐☐☐☐☐☐☐
		BH	☐☐☐☐☐☐☐☐☐☐
IV. OVERALL EVALUATION			
How does the ratee compare with others of the same grade and Air Force specialty? Potential for promotion and increased responsibility are essential considerations in this rating.			0 1 2 3 4 5 6 7 8 9
	RATER		☐☐☐☐☐☐☐☐☐☐
	1ST INDORSER		☐☐☐☐☐☐☐☐☐☐
	2D INDORSER		☐☐☐☐☐☐☐☐☐☐
	3D INDORSER		☐☐☐☐☐☐☐☐☐☐

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AIRMAN PERFORMANCE REPORT
(Airman Basic thru Senior Airman)

Figure 1-2. Airman Performance Report.

8. Which AFSC identifies the position to which you are assigned?

003. Relate the AFSC to promotions, and identify the factors which are considered in the Weighted Airman Promotion System.

Airman Promotions. Career progression from one grade to another is a significant part of your Air Force life. The present system provides personnel in every AFSC equal opportunity for promotion. Your eligibility for promotion is based on your skill level, time in current grade, time in service, and your commander's recommendation. Promotion to E-2, E-3, or E-4 is noncompetitive. You are recommended by your squadron commander when you are eligible and qualified. Additionally, you are eligible for early promotion to E-4, on a best qualified basis, provided you meet the date of rank criteria announced by the Air Force Manpower and Personnel Center (AFMPC) and are recommended by your squadron commander. This below-the-zone promotion is highly competitive. Qualified airmen are recommended by their supervisors to compete before a squadron board of select NCOs to determine the best qualified. These best qualified airmen are then recommended by their squadron commanders to compete before a central base board. Those selected by the central base board may be promoted up to 6 months before other fully qualified airmen.

Your supervisor may or may not recommend that you compete for a below-the-zone promotion based on your performance in your duty section. Study Sections III and IV of the AF Form 909 in figure 1-2. These are the areas in which your supervisor will evaluate and rate you. The squadron board and the central base board will review your performance reports, as well as ask you questions about current events and general military knowledge.

Weighted Airman Promotion System (WAPS). The WAPS selects airmen for promotion to the grades of staff sergeant (E-5) through master sergeant (E-7). Basically, WAPS selects airmen for promotion on the basis of the total score of certain validated factors.

The weighted or validated factors are as follows:

Specialty Knowledge Test (SKT). The SKT measures your knowledge concerning your Air Force Specialty (AFS). This test is administered annually, with a possible score of 100. This CDC is your study reference for the SKT.

Promotion Fitness Examination (PFE). The PFE measures your knowledge of military subjects and management practices at a specific grade level. The PFE is normally administered at the same testing session as the SKT, with a possible score of 100. Air Force Pamphlet 50-34 is your study reference for the PFE.

Time in service (TIS). TIS is computed by awarding 1/6 point for each month of active Federal military service (AFMS), up to the total possible score of 40 points for 20 years of active service as of the last day of the month of the promotion cycle. A period of 15 days or more counts as 1/6 point, and periods less than 15 days are dropped.

Time in grade (TIG). TIG is figured at the rate of 1/2 point for each full month in grade. Over 15 days of a month counts as 1 whole month. The maximum obtainable is 60 points.

Decorations. Decorations are assigned specific points according to their order of precedence. They range from 1 point for the Purple Heart to 15 points for the Congressional Medal of Honor. The same points will be given for repeat awards, or for equivalent awards earned in other military services of the United States. A total of 25 points is maximum.

Airman Performance Report (APR). The APR is used to measure your past job performances. It reflects the sum total of your capabilities as demonstrated in your daily actions. It indicates your expected duty performance in future assignments within your career field. APRs are computed by taking an average of the overall ratings of the last 5 years of APRs and multiplying the average by 15; maximum points are 135. The APR score counts for more than one-fourth of the total WAPS score possible.

One of the main features of the WAPS is its visibility. You'll know exactly what you're being judged on in comparison with others of the same grade and Air Force specialty. You can see the importance of each promotion factor and its weight. You can even figure your own score on the known factors. If you are not selected for promotion, you will receive a written notice showing the scores you obtained on each factor, your total point score, and the total score for promotion of the last airman promoted during that specific promotion cycle in your AFSC. This visibility feature will show you where you might improve your promotion potential.

Improving your technical and educational level is a continuous process. Throughout your career, you will be striving to improve your own competence, as well as the overall competence of your shop. As each of you do your best at your individual jobs, the entire Air Force maintenance system becomes more efficient and more effective.

Exercises (003):

1. Who recommends airman promotions to E-2, E-3, or E-4?

2. When are promotions to E-2, E-3, or E-4 recommended?

3. How could you be promoted to E-4 as much as 6 months early?

4. What are the six factors considered in the WAPS?

5. What does the SKT measure?

6. Which WAPS factor measures your knowledge of military subjects and management practices at a specific grade level?

7. How is time in service computed for WAPS?

8. Which of the weighted factors should you be able to improve by studying?

9. Which weighted factor tells how well you have done your job?

NOTE: For objectives 004-046, study objectives 001-043 in Module 10009, *On-the-Job Training*, which accompanies this volume. When you have completed Module 10009, return to the text.

Module 10009

On-the-Job Training

CDC 32551-1 Objectives	*Module 10009 Objectives*
004	001
005	002
006	003
007	004
008	005
009	006
010	007
011	008
012	009
013	010
014	011
015	012
016	013
017	014
018	015
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021	018
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031	028
032	029
033	030
034	031
035	032
036	033
037	034
038	035
039	036
040	037
041	038
042	039
043	040
044	041
045	042
046	043

Security

THE NATIONAL Security Act of 1947 established our Air Force and made it responsible for a major role in our national defense. This is a serious business requiring highly trained personnel, complex equipment, and expensive materials. We cannot afford to be careless with any of these resources, because our enemies are constantly committing hostile, subversive, and destructive acts to weaken and destroy our Nation and its Armed Forces.

2-1. General Security

Like safety, the security of our resources and information is totally dependent upon each of us all of the time. Just because you do not handle material which has been marked "CLASSIFIED" does not mean that you could not give classified information to our enemies. You often work on aircraft which may contain classified instruments or other equipment. Just the fact that the equipment is used on that particular type of aircraft may be classified. Therefore, you have access to or have classified information that must be protected.

047. Identify security program publications and tell why they may be supplemented.

Publications. The methods and procedures for the protection of vital defense information can be found in DOD 5200.1-R/AFR 205-1, *Information Security Program*. This regulation is the basic Air Force document governing security. Your squadron security officer, whom you should know, should have a copy of this regulation. It establishes policies for safeguarding classified information and explains how to identify, classify, and protect such material. This regulation is directive and applies throughout the Air Force. Major commands (MAJCOMs) and their assigned units may supplement DOD 5200.1-R/AFR 205-1 particularly in the procedures for safeguarding classified material peculiar to that command. Classified material, which may be peculiar to a command, comes in many forms, such as:

- Documents.
- Manuals.
- Tests.
- Information.
- Notes.
- Equipment.
- Operation of weapon systems.

Obviously, the importance of classified material determines the manner and extent to which it is protected.

Exercise (047):

1. Why would a major command need to supplement DOD 5200.1-R/AFR 205-1?

2. What document is the basis of the Air Force security program?

3. Who may supplement DOD 5200.1-R/AFR 205-1?

4. What determines how classified material is safeguarded?

5. What information is provided in DOD 5200.1-R/AFR 205-1?

048. Explain how and why information is classified, list the classifications, and identify them.

Classification of Information. All Air Force information is official and should be treated as such, regardless of classification. Official information is defined as "information owned by, produced by, or controlled by the United States Government." Official information which requires protection in the interest of national security is limited to three categories. They are, in descending order of importance, Top Secret, Secret, and Confidential. Information about aircraft systems may be classified in any of these categories.

Top Secret applies to that information or material which requires the highest degree of protection. The unauthorized disclosure of Top Secret information could reasonably be expected to cause *exceptionally grave* *damage* to our national security. Examples of "exceptionally grave damage" include armed hostilities against the United States or its allies; disruption of foreign relations vitally affecting the national security; the revelation of sensitive intelligence questions; the compromise of vital defense plans; and the disclosure of scientific or technological developments vital to our national security. Although the part you or your unit plays in a defense exercise may seem unimportant, that information, coupled with information from another unit, could give insight into a Top Secret defense plan.

Secret refers to that information or material which requires a substantial degree of protection. The unauthorized disclosure of Secret information could reasonably be expected to cause *serious damage* to the national security. Examples of "serious damage" include compromising important military defense plans; revealing important scientific or technological developments; or revealing important intelligence operations. You may be required to know the strategic operating limitations of some of our aircraft in the performance of your job. You may be in a position to know about the storage or movement of nuclear weapons. Improper disclosure of such information could seriously harm our defense efforts and therefore could be classified as Secret.

Confidential applies to that information or material which requires protection. The improper disclosure of Confidential material could reasonably be expected to cause damage to the national security. Some technical orders, local operating procedures, equipment test results, troop movements, or even the number of personnel assigned to your organization may be classified as Confidential.

Exercises (048):

1. How is classified information categorized?

2. List the categories of classification in descending order of importance.

3. Define the classification category "Top Secret."

4. What is the classification of information which, if disclosed, could result in serious damage to the national security?

5. What could result if Confidential information is disclosed without authorization?

049. Explain the safeguarding of information.

Safeguarding Information. All Air Force information is official information. It is defined as "information owned by, produced by, or controlled by the United States Government." Classified information is information that is withheld from the general public, other military members, and even other Government agencies. No one is entitled to the knowledge or possession of classified material or just because of his or her rank, job, or desire. Classified material is given only to those individuals whose official duties require its knowledge or possession. The fact that you possess a Secret clearance and a restricted area badge does not gain you admission to every restricted area or access to all classified documents. You must have a valid need to know, as well as the required security clearance.

The individual possessing classified material is solely responsible for determining if your duties require you to have access to the material. If you have a classified document, such as a technical order, you are responsible for it; and you must determine who has a need to know. But, you are not to disclose classified material unless specifically authorized to do so. No one is granted access to classified material just for being where such material is kept.

Classified material must be continuously protected during its use. It must not be exposed, discussed, or revealed orally in the presence or hearing of authorized persons, including those who have access authorization but no need to know the information.

Classified material may be used only in locations where it can be safely stored and properly protected. It must be under the direct control of an authorized person, guarded, or stored in an approved locked container at all times. Top Secret information will not be reproduced without the consent of the originating activity or higher authority. All other classified material can be reproduced sparingly, in the very minimum number of copies, and any stated restrictions for reproduction will be strictly observed. These procedures apply to any classified technical orders you use or may have the occasion to use. All reproduced copies must be protected.

Safeguarding classified material is everyone's responsibility. You must be conscious of the security elements and risks involved in your job. You need to understand the security aspects of your organization. Your organizational requirements determine the security measures you must take to safeguard military information. Your organization may have problems for which no regulation gives an answer. In such cases, local directives (supplements) specify the methods and procedures needed to provide the required security.

Your security consciousness is demonstrated by your ability to discuss your work without divulging any of its classified elements. The exchange of ideas is necessary and desirable, but you must use caution. YOU make the security program work.

Exercises (049):

1. Does a person with a Secret clearance have access to

all Secret information? Briefly explain your answer.

2. Who is responsible for a classified document when it has been removed from a classified file?

3. Should a file clerk of a classified file have a working knowledge of the information on file? Briefly explain your answer.

4. An airman is studying a Secret document to determine the procedures for fixing a malfunctioning component. The squadron commander enters the area and asks to read the document. Who makes the determination as to the commander's need to know?

5. When you must discuss your work, what precautions must you take in regard to security?

6. Who makes the security program work?

7. Who is authorized to possess classified material?

2-2. Communications Security (COMSEC)

We have covered only the general security information necessary that you need to know for upgrade to the 5 skill level. Additional information is contained in AFP 50-34. You will have to study this pamphlet in order to successfully compete for promotion under the Weighted Airman Promotion System.

Now let's discuss the area where we are most likely to violate good security practices. We have discussed the fact that you are the backbone of the security program. If you do not divulge the classified information you know, then our enemies are short one source. You already know that you should not discuss your knowledge with any unauthorized person. In fact, the best thing for you to do is to talk shop only at the shop. The easiest place to compromise our entire security effort is over the telephone. Everyone, at some time or another, is confronted with the situation where an urgent need to get the job done seems to indicate that security procedures should be bent just a little. Don't you believe it! Communications security should be one of your prime areas of training and concern.

050. Associate methods of transmitting classified information with situations where each may be applied.

Air Force Communications Methods. In addition to radio and the ordinary telephone (which we discuss later), five methods of communication are used frequently by the Air Force. Three of these methods are electrical transmissions, as follows:

a. AUTODIN (automatic digital network).
b. AUTOSEVOCOM (automatic secure voice communications).
c. AUTOVON (automatic voice switching network).

The other two methods are these:

a. ARFCOS (Armed Forces Courier Service).
b. U.S. Postal Service (USPS) mail.

We shall discuss each of these methods briefly and explain whether they are to be used for transmitting classified material.

AUTODIN: AUTODIN is a communications network for the transmission of logistical, operational, statistical, and administrative messages. The messages can be encrypted; therefore, the network can be used for classified or unclassified messages of intelligence value. This system automatically produces copies of the messages.

AUTOSEVOCOM: AUTOSEVOCOM is a secure communications network. This system is a long-distance telephone and radio network and is used for worldwide communications between military establishments. It provides for protection of classified or unclassified information of intelligence value.

AUTOVON: AUTOVON is an unsecure communications network. This system is also a long-distance telephone and radio network used for worldwide communications between military establishments. But it does not provide protection for classified or unclassified information of intelligence value. You should never use this system to transmit any information of intelligence value.

ARFCOS: ARFCOS is a communications method that uses selected personnel as messengers. These messengers are used to receive, transport, and deliver classified documents and equipment to United States installations around the world.

USPS: U.S. Postal Service mail includes both regular and registered mail. Registered mail can be used, under certain conditions, to transmit classified material; regular mail does not provide for protection of classified material.

SLOW	FAST		SECURE	INSECURE
X		ARFCOS	X	
	X	AUTOVON		X
	X	AUTOSEVOCOM	X	
	X	AUTODIN	X	
X		U.S. MAIL		X

Figure 2-1. Air force communication methods.

Selecting the proper communications method. When any information is to be transmitted, you must consider the security, speed, and reliability of the method to be used. Both the advantages and disadvantages of each method must be weighed. Now let's look at some examples.

Characteristics of ARFCOS.

Speed: One-day delivery within the United States: 1 to 3 days overseas.

Security: Secure, under armed guard while in transit.

Reliability: Reliable; correspondence is always receipted for.

Characteristics of USPS (registered).

Speed: Slow; 1 to 3 days within the United States; 3 to 7 days overseas.

Security: Limited security because of special handling.

Reliability: Can be used under certain conditions because of the receipt system.

Characteristics of USPS (regular).

Speed: Slow; same as registered mail.

Security: Insecure; handled by many persons without a need to know.

Reliability: Unreliable; no receipt system.

Each of the five methods of communications can be considered slow or rapid in relation to the others. Each can also be considered secure or insecure in relation to the others. Take a look at figure 2-1 and see how the five methods compare.

Let's look at a couple of hypothetical situations that involve the transmission of information and the best method suited for the situation.

Situation: Sergeant Whitcomb, who was TDY at Wright-Patterson AFB, encountered a technical problem involving the weapons system of a new fighter plane. He wanted to get in touch with his home base to help solve his problem. The information that he needed was classified, and an answer was needed as soon as possible. He decided to call his home base on the AUTOVON. Was he right or wrong in his decision?

Because he required classified information, he was wrong in his choice of AUTOVON. If you recall, AUTOVON is an insecure communications network. It could be tapped quite easily. He should have used AUTOSEVOCOM, which is a secure voice communications network.

Situation: Airman Macy had just completed an extension course. She had a question concerning the manner in which air compressors were presented in the text. She sent an inquiry to ECI headquarters through regular U.S. Postal Service mail channels. Was she right?

In this case, regular USPS mail was the most feasible method to use. The airman was not pressed for time and no classified information was involved.

Exercise (050):

1. Specify the proper method of transmission for each situation given in column A by placing the letter of its corresponding type of transmission found in column B. NOTE: Each item in column B may be used once or not at all.

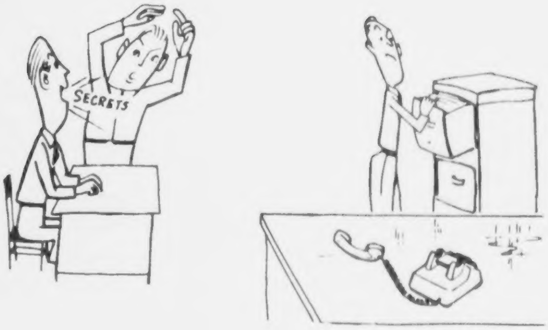
Column A	*Column B*
Situation	*Types of Transmission*
____ (1) A 300-page document classified Secret has to be distributed to all European Air Force bases within 1 week.	a. AUTODIN.
____ (2) Within 5 hours, Captain Ecker has to have a classified single-page message in the hands of three base commanders in a war zone.	b. AUTOSEVOCOM.
____ (3) A civilian employee for a nuclear arms development center must transmit some classified information to another base immediately.	c. AUTOVON.
____ (4) You have a request for an official document from Scott AFB Il.	d. ARFCOS.
____ (5) You have 24 hours in which to send a Secret document to a base that is 200 miles away. The document consists of a 3-volume 500-page report.	e. U.S. Postal Service.

051. Identify voice communications, weaknesses and security violations associated with voice communications.

Voice Communications. Voice communication is the sending of information by any means using the voice. Examples of voice communication are commander's call, telephone conversations, social gatherings, and radio transmissions. Because of the frequent need to communicate by voice, you need to be conscious of possible violations and precautions at all times. A basic rule to remember is that the need for protection will generally exceed the need to convey sensitive information.

The telephone is the weakest link in our communications system. A basic security weakness of telephone use results from the range of the system. The remoteness of telephone wires and relay stations as well as unknown telephone operators and long-range radio relays permit unauthorized people to listen in on any of our conversations. Because electronic devices ("bugs") are readily available to anyone, an unfriendly agent can listen in on telephone conversations with little difficulty.

Another security factor you need to keep in mind is the sensitivity of the telephone transmitter or mouthpiece. It is able to pick up noises and conversations in the background just as well as it can pick up your whispers, as shown in figure 2-2. When using the telephone, you must assume that you have uninvited listeners and that none of them has a need or a right to know. This means that you should never discuss any information that is classified or of possible intelligence value, and, you must take care that all background conversations are not transmitted over the telephone.



UNAUTHORIZED LISTENER ON THE PHONE ?

Figure 2-2. Background noises.

Common Telephone Security Violations. Security violations occur quite frequently because airmen incorrectly assume that the risk is justified.

Being trapped by time is no reason to risk disclosure of sensitive or classified information. This condition frequently occurs because of poor planning and unforeseen mission or job requirements.

Fear of rank or position such as the "call from Colonel Emerson at headquarters," causes some airmen to forget or ignore proper security procedures. This should never happen. Always remember, no matter who calls from a higher headquarters, the telephone is not to be used to discuss or provide classified information or information of possible intelligence value.

Conducting personal business is another practice that can lead to the disclosure of classified information. You must remember that the telephone is in your shop to conduct official business only. If, over a period of time, your friend calls the shop enough to learn the names of everyone in the shop and finds out what goes on in the shop, could this be a security risk? Yes. It definitely could be.

"Talk around." Attempting to "talk around" classified or sensitive information is a big security risk. This means trying to send the information in such a way as to protect it, yet to get the point across.

"Talk around" is usually easy to recognize. It is using words that are not supposed to make sense to anyone except the one for whom the information is intended. Calling a classified part of a radar or instrument system a "gizmo" might be an example of attempting to talk around. But no matter how much you change the words, the subject is still classified. Anyone who goes to the trouble to listen in on your conversations probably knows enough to "read through" your attempts to talk around.

Unclassified gossip. Chatter, idle, or unnecessary talk is another type of security risk. Anytime you use an official telephone to "shoot the breeze" with a friend, you are engaging in unclassified gossip. When you make small talk by asking, "How are things over there?" or "Is old so-and-so still in your section?" you are engaging in unclassified gossip. A security risk arising from unclassified gossip is the ever-present risk of associating persons or subjects with a specific job or section. Your questions may tempt your friend to reveal classified information.

Self-made reference systems. Using self-made reference systems to refer to information that is classified or of possible intelligence value is a very definite security risk. You may believe that you are clever enough to refer to an item of information without actually revealing names, subject, etc., but this technique rarely succeeds from a security standpoint. Self-made reference systems may be anything, but a simple one might sound like this: "Well, let's see now, subtract today's date from the form number 107, and you have the total." Anyone who overhears this conversation can subtract the date from 107 and get the total.

Here are some other examples of using a self-made reference system:

a. "Next year we are going to be flying the same models that you guys at Hailstrom AFB have."

b. "The new aircraft will fly as fast as the old F-86."

c. "Our departure time is classified, but we leave one-half hour earlier than you left yesterday."

d. "I cannot tell you the payload of the new one, but it is equal to two of the ones you are now flying."

As with "talk around," anyone who takes the time to listen in on your conversations is willing to take the time to read through your self-made reference system.

Paraphrasing. Another close neighbor of talk around is paraphrasing. "Paraphrasing" means changing the words but not the meaning. Some examples of paraphrasing are:

a. "I cannot tell you who the VIP is, but he is the Vice President's boss."

b. "Our number one boss here will leave for your operations center at 0730 tomorrow."

c. "Your flowing locks must be abbreviated before regular duty time tomorrow."

The major difference between talk around and paraphrasing, is that talk around employs invented words, or "gobbledygook," while paraphrasing does not. Both techniques are security risks when they are attempts to disguise classified or sensitive information.

Using code words and nicknames. Another method of trying to disguise information in voice communication is the use of code words and nicknames. A code word is a classified word with a classified meaning, while a nickname consists of two words that are classified. When used in Air Force communications, the word "Chicago" could be a code word; the word "Burnt match" could be a nickname for an exercise. Both code words and nicknames are valid attempts to disguise in communications, but neither should be used in any telephone conversations.

Emotional outbursts. Displays of strong emotions can be another security risk. If people become impatient, angry, or hasty when using the telephone, they are likely to say something they shouldn't. Have you ever seen anyone try to explain something on the telephone and become angry when he or she could not get the point across' In conducting official business, this could be a security risk.

Other voice communication security violations. We are not suggesting that you or any other Air Force member would ever knowingly give information to or help the enemies of our country; but, many United States citizens do provide such information or help, just by talking too much. We have already discussed some of the security risks that could occur when you use a telephone. Most of them can also occur in face-to-face conversations at any time or place. Talk around, emotional outbursts, gossip, etc., can run wild at a social gathering. You can avoid such security risks if you will simply remember that talking about your work should be confined to your official duties. Never discuss your duties, the place where you work, or the equipment you maintain in a public place or even at a private party. Develop the habit of avoiding any discussion of your military activities with unauthorized people.

Exercise (051):

1. Match each type of telephone security violation in column B with the situation involving it in column A, by placing the letter of the violation in the blank. Column B items may be used once or not at all.

Column A

Situation

___ (1) "On pages 7 and 26 of the gizmo, where it reads '8' we need to change it to '10' because of additional workload from your section."

___ (2) During lunch hour, two airmen were discussing the events of the coming week. One said he would not be able to go fishing Thursday because his section was starting work on a new project.

___ (3) You receive a call from a general requesting some specific information. You think the information is of possible intelligence value, but since it is a general you provide the information.

___ (4) Airman Stevens works down-town at a gas station when off duty. One day you hear him use the office phone to call his civilian employer. While Stevens is on the phone, other personnel in the office are discussing classified information.

___ (5) During a telephone conversation, you are told "I can't tell you its speed, but it can fly from New York to Seattle in 1 hour and 50 minutes."

___ (6) A monitored radio message has associated the nickname "Red Dog" with a bombing mission.

Column B

Telephone Security Violation

a. Trapped by time.
b. Fear of rank or position.
c. Conducting personal business.
d. Talk around.
e. Unclassified gossip.
f. Self-made reference system.
g. Paraphrasing.
h. Using code names and nicknames.
i. Emotional outbursts.

2-3. Physical Security

Physical security deals with threats of physical damage to Air Force resources or property, as opposed to personnel security, safeguarding defense information, or security against espionage and subversion. The Air Force Physical Security Program is designed to produce direct and indirect influences which will deter any enemy from attempting hostile acts against the Air Force. The basis of the program is the conviction that effective security measures will convince any enemy that tremendous risk and penalties will result from any attempt to impair our Air Force capabilities.

Except for our top priority (Priority A) resources, using organizations are responsible for the security of our aircraft and equipment. Every member of the Air Force must bear his or her share of security responsibility.

052. Relate terms, security measures, and reports to the protection of Air Force resources and the response requirements for detected suspicious or hostile acts.

Security Terms. Before we go further into this discussion, you need to know the following items:

Clandestine—activities conducted in secrecy.

Sabotage—any act intended to destroy material, equipment, buildings, etc., or hinder the war-making capability of the U.S. Armed Forces.

Espionage—spying to obtain military secrets.

Subversion—action taken to lower the loyalty, morale, or discipline of personnel.

Terrorism—the use or threat of force or violence to accomplish political goals.

Covert—hidden.

Overt—open, unconcealed.

Sabotage, espionage, and terrorism can be conducted in an overt or clandestine manner.

Security Measures. Because it has nuclear weapons and can strike quickly at any attacker, the Air Force is at the top of the target list of enemy groups, both in the United States and abroad. The Air Force knows that every base cannot be guarded completely from attack by hostile groups; but, with proper security measures implemented at all levels of command, the Air Force can discourage any overt or covert acts of sabotage or terrorism, and hinder attempts of espionage and subversion.

Enemy agents often try to meet and make friends with Air Force people. Radical groups also search for Air Force members or employees who look like they can be used to cause problems or create incidents that will hurt the discipline or morale of an Air Force unit. Any of us could be used to provide unauthorized access to a military installation, facility, or information.

If the proper authorities are not told of matters that affect the security of the Air Force they cannot take the right defensive actions. Thus, all Air Force members and employees must tell their supervisors, commanders, or Air Force Office of Special Investigation (AFOSI), as soon as possible about any contact with citizens of a communist country; any request for defense information, document, publication, equipment, or access to an installation or facility that is not made through official channels; and any known or suspected attempt to sabotage defense property.

There are two things we can do to protect our Air Force. The first is to refuse to help our enemies by practicing security consciousness at all times. The second, which is equally important, is to report all suspicious acts, requests, and contacts immediately.

Reporting. The Air Force has established an effective high-speed security reporting and alerting communications network that links all bases so that reports of hostile events and security alerting orders can be sent to all bases immediately. Two types of reports in the security reporting and alerting system are identified by the standard code names of "Helping Hand" and "Covered Wagon." It is possible that you could initiate either of these reports.

(1) Helping Hand. This report means that a possible hostile event or action that could affect the general warmaking capability has been detected. While you are working on the flight line, you may see an unauthorized individual approach an aircraft with an obviously out-of-place package. You call out and the person throws the package under an aircraft and starts to run. You should detain the individual if possible, but you should yell "Helping Hand" in any case. This will alert other personnel of the threat, obtain assistance for you, and initiate a relay of the report of the discovery to the security police and other authorities.

(2) Covered Wagon. This report means that a condition exists or an event has occurred at a base as a result of actual or probable hostile action. If, in the incident outlined above, the package exploded and damaged the aircraft, it would probably be reported to higher headquarters as a Covered Wagon report.

Security Force. The Air Force has also established a security force for armed response to counter hostile threats. This is a function of your base Security Police. This security force must be able to expand into an emergency force by using additional personnel as necessary. You could be utilized as a security force augmentee.

Security plan. A base security plan (OPLAN) has been established for every Air Force base. This plan provides detailed guidance for conducting normal and emergency security operations, with the central security control (CSC) office of the base Security Police as the operational command post.

Restricted areas. Each base establishes restricted areas to protect critical operational resources. These include, but are not limited to, command posts, aircraft parking areas, maintenance shops, motor pool, and alert facilities. Restricted areas are posted with signs, fenced, and/or guarded.

Training. Finally, all personnel are trained and used in security procedures. You can protect our Air Force and its resources. You can challenge anyone whom you suspect as being a security risk.

Exercises (052):

1. Match the terms in column A with the definitions in column B. Some terms may be defined once or not at all.

Column A	*Column B*
____ (1) Sabotage.	a. Use or threat of force or violence to accomplish political goals.
____ (2) Clandestine.	b. Activities conducted in secret.
____ (3) Covert.	c. Hidden.
____ (4) Espionage.	d. Any act intended to destroy property or hinder warmaking capability.
____ (5) Subversion.	e. Unconcealed.
____ (6) Terrorism.	f. Spying to obtain military secrets.
____ (7) Overt.	g. Action to lower the loyalty, morale, or discipline.

2. Give two reasons why the Air Force expects to be at the top of the target list of enemy groups.
3. What should you do if a salesman asks you for a copy of the base telephone directory?
4. What two things can we do to protect the Air Force?
5. What are the two types of reports in the security reporting and alerting system?

053. Identify control procedures for entry into a restricted area.

Restricted Area Entry. Basically, personnel entry control procedures are security measures designed to deny unauthorized persons access to critical operational resources. This is the objective of all entry control systems. The Air Force has tried to keep the systems compatible with the duties, schedules, and work procedures of affected personnel. These procedures currently meet their objectives without hindering the operations, maintenance, and similar official activities performed in the restricted areas. Only those persons absolutely needed to perform necessary tasks are allowed to enter.

Entry control procedure. The basic objective of any entry control procedure is to verify the right of each person to enter the restricted areas. One or more of the procedures described below will be used to establish a person's identity and verify his or her authority to enter a restricted area.

Exchange badge procedure. This method uses two badges for each person. One is issued to the person requiring the badge. The other—similar to the first except for a distinct color—is held by the restricted area guard.

When entering or leaving the restricted area, the person must swap the badge possessed with the one held by the restricted area guard. This has proven to be a positive control identification and verification technique.

Single badge procedure. This entry-control technique involves only one badge for each person who needs to enter the restricted area. All personnel who have to work on the flight line will normally have a restricted area badge. The photograph and other descriptive data on the badge are compared to the features of the person possessing the badge. Because, by itself, any single badge procedure can be defeated with relative ease, one of the following identification and verification techniques is often used to support it.

Personal recognition. This is a valuable and reliable method of identification when used as a formal procedure, where a small number of people are working together.

Signature and credential check. When this procedure is used, an individual is asked to sign his or her name. This signature is then compared against the DD Form 2AF, Armed Forces Identification Card, driver's license, or other credentials, as when cashing a check at the bank.

Telephone and radio verification. This procedure requires prior notification of central security control (CSC) of an individual being sent to the restricted area. CSC will inform the entry guard that a specific individual will be entering the restricted area.

Sign countersign systems. This is basically where one must give the proper code (password) word in order to enter the restricted area. The guard will say a specific word or phrase, which is the sign, and you must give a predetermined reply, which is the countersign.

Exercises 053:

1. What type of procedure is used when you give the restricted area guard your badge and the guard gives you another badge which you must wear?

2. What type of procedure is used if you have to sign your name and show your ID card?

3. What is the verification procedure that can be used where relatively small numbers of people are working together?

4. What verification procedure is used when the restricted area guard is told to expect your arrival for entry into the area?

5. What is the objective of all entry control systems?

054. Identify the restricted area badge according to its purpose, description, and use.

The Restricted Area Badge. The Air Force restricted area badge is a serially numbered accountable form, which is available in several colors. It is an official document that is used to identify individuals who have been granted unescorted entry authority only. It is not used for routine identification purposes. When it becomes necessary, you will be issued one. Your badge will have your picture on it, as well as other pertinent identification data. A series of numbers are provided on every badge to indicate the particular numbered areas on the base that you will be permitted to enter. Unused numbers will be blocked out. If you will be required to escort visitors into the restricted area, you must have a capital letter E typed or stamped on the badge beside the number of the restricted area.

The restricted area badge has a button tab or snap clip so that it may be attached to your outer clothing. You are responsible for the security of your badge. It must always be visible when you are inside the restricted area and it must be removed when you are outside of the restricted area. Also, keep in mind Air Force Regulation 35-10, *Dress and Personal Appearance of Air Force Personnel.* When your badge is not in use, the button tab or snap clip should not be visible on the uniform. This means that it is improper to wear it tucked under the collar or inside the front of the shirt with the fastener visible.

Unescorted entry. In determining if you qualify for unescorted entry authority for a restricted area, the frequency of your being needed in the area and your security clearance will be the determining factors. Most aircraft maintenance specialists qualify for unescorted entry to aircraft parking areas.

When a need to enter is established, a person may enter by being granted unescorted entry authority (given a restricted area badge) or by being escorted.

Escorted entry. Escorted entry procedures will be used for all other personnel who may be needed within the restricted area, but who do not qualify for unescorted entry authority. This includes personnel requiring entry into a restricted area on a one-time basis, or to perform duties on an infrequent "on call" basis. Examples of such personnel are civil engineers, utility repair crews, and certain staff personnel.

Escort officials selected for each restricted area must be strictly limited to personnel who hold responsible supervisory positions. These people must be able to make valid determinations about official needs for persons to enter the restricted area. The number of escort officials for each restricted area is kept to an absolute minimum, just enough to meet operational requirements.

Procedures for escorting personnel. When a person requires escorted entry, a designated escort official, bearing a properly annotated USAF restricted area badge, will meet the person at the area entry point. The escort will confirm the person's need to enter and insure that the person is escorted until departing the restricted area. An escort official's most important duty is to determine whether or not a person should be permitted to enter the restricted area. The escort official is responsible for the actions of the person being escorted, and must insure that the person is escorted out of the area when the work is done. A person who has been permitted to enter, based on an escort official's authorization, should be escorted and closely watched continuously while in the restricted area. This can be accomplished in several ways.

a. The escort official stays with the person until the job is done and the person has left the restricted area.

b. The escort official may assign another individual within the area to stay with the person until the job is done and the person has left the restricted area.

c. If a person is to be involved in a task at a specific point or zone within the area, the escort official may, by coordinating with CSC, establish a free zone where the person may work. The escort official must appoint persons in the immediate proximity of the free zone to fulfill the requirements of the escort by watching the person closely while they continue to do their own jobs.

In all instances, the escort official must explain the rules concerning movement within the restricted area to persons escorted.

Exercises (054):

1. What is the purpose of the restricted area badge?

2. What is the series of numbers on the restricted area badge for?

3. If the letter E is placed next to a number on the badge, what does this indicate?

4. What qualifies an individual as eligible for being issued a restricted area badge?

5. Who will be selected as escort officials?

6. When an individual asks to be escorted into a restricted area, what is the most important function of the escort official?

7. May the escort official designate another person to escort an individual?

2-4. Operational Security (OPSEC)

From preceding discussions of security, you know that classified information must be safeguarded by physical means, by limiting dissemination, and by not discussing classified information in unsecure areas or using unsecure methods of communication. You have learned specific facts about Air Force communication systems and how unclassified conversations could provide our enemies with possible valuable information. Now, your security consciousness needs to be directed toward emergencies, as well as normal peacetime operations.

This section covers the Air Force Operational Security (OPSEC) Program. This program promotes the successful execution of peacetime operations. It applies to all peacetime and wartime missions.

055. Explain the purpose of OPSEC, give reasons why OPSEC is necessary, and determine applications.

Directive. The Air Force OPSEC Program is covered in AFR 55-30, *Operations Security*. OPSEC is an overall security program designed to enhance mission effectiveness. It deals with the protection of information and activities that are sensitive in the sense that they telegraph our punch to an enemy; they can warn an enemy of our plans.

Definition of OPSEC. A simplified definition of operational security is "The protection of classified and unclassified information about a military operation that could aid the enemy, if revealed."

Purpose. OPSEC is intended to reduce the capability of an enemy to gather useful intelligence data about our operations and activities. One of the basic principles of war deals with the element of surprise. OPSEC is concerned with keeping tactical and strategic advantage on our side by protecting information and activities affecting our plans, resources, and limitations. The proper protection of classified information and material is part of it; so is the protection of seemingly trivial or insignificant, unclassified information and actions.

The success or failure of most major combat operations is contingent upon the element of surprise. Before an operation can be kicked off, personnel must be assembled, equipment and transportation gathered, and many other activities completed. Usually, definite patterns of behavior or action are followed, and these patterns can become warning signs to enemy intelligence collectors. Trying to gain information about planned operations is not new; it is an age-old practice.

Scope. The first Air Force OPSEC program dealt with the problems of combat operations security in Southeast Asia. The present OPSEC program, established in 1970, includes all personnel and agencies connected with or having knowledge of any operation, event, project, or program. Any information that could help a known or unknown enemy is to be protected.

Sources and types of information. There are many sources or possible sources of information that could aid an enemy. Generally, these can be placed in one of three categories common to any military activity: operations, procedures, and communications. Examples of the types of information within these categories are:

- Objectives of an operation.

- Operation time and location references.
- Friendly and enemy forces involved (troops, ships, planes, tanks, etc.).
- Known or suspected limitations.
- Methods of employment or use.
- Results of an operation.
- Sources of intelligence data (where we got our information; where any enemy might obtain information).
- Methods of collecting data.

Vulnerability. Aircraft maintenance people use a lot of possibly sensitive information in their normal duties. This information may be in the form of scheduled practice exercises, actual wartime missions, flying schedules, names of key personnel, or exercise or target code names. The information could come from flight crew members on the flight line or in debriefing, discussions overheard in Quality Control, Maintenance Control, or almost anywhere within the maintenance complex.

Suppose, for example, that while in debriefing, you overheard a conversation on why a particular mission could not be accomplished. Maybe you are in Maintenance Control and you overhear a conversation about the takeoff times and destination of special aircraft missions. Would it be an OPSEC violation if you later repeated this information in the BX cafeteria? Although take-off times, destinations, or even in-flight problems may not be classified, they are surely sensitive. The takeoff times, when added to other pieces of sensitive information, could give insight to a classified mission. Problems encountered in flight could identify systems, equipment, or aircraft classified limitations.

Sensitive information that you read or hear may not be labeled as such. You must use your own judgment. If you have any doubt about any piece of information, treat it as sensitive.

All the forms of security contribute to the one objective of mission effectiveness. Information security, communications security, physical security, the prevention of espionage and sabotage, and OPEC, all enable us to maintain an advantage over a possible enemy by denying that enemy information about our activities and plans. None of the security programs stands alone; they all contribute to the common goal.

Exercises (055):

1. What is the purpose of OPSEC?

2. What type of information is considered sensitive?

3. To whom does the OPSEC program apply in the Air Force today?

4. Which of the following statements could be considered sensitive when heard outside of your shop environment? Explain why.
   a. Did you get your shots for Korea?

   b. I can't go to the game tonight because of the special mission coming up.

   c. There sure has been a lot of maintenance to do lately.

   d. Our flight has target X and Y tomorrow.

   e. All of these late night refueling missions must stop.

Occupational Safety and Health

"BUT MOMMY, it was an accident"! Could this be your child? If so, did you cajole, pet, or otherwise make everything all right for the child?

"But Sir, it was an accident." Could this person work for you? Do you cover it up—or what? Can you imagine yourself saying these words to your boss? These words or similar words are heard everyday.

Accidents do happen—they happen when we are working or playing, at home or on the job. These "so called" accidents happen all too frequently. Yes, we said "so called" accidents. A true accident, if there is such a thing, is a rarity. ACCIDENTS ARE CAUSED! If we can find or determine the cause, we can prevent a similar accident. Thus, we arrive at accident prevention. This is the primary principle behind all safety programs.

3-1. Basics of Air Force Safety

The United States Government, the Air Force, and you believe accident prevention to be valid. Let's start with you. When you were a child, you may have burned your hand or fingers on a hot stove. It hurt, so, you figured out how to keep from burning yourself the next time. You implemented what is known as accident prevention.

On a larger scale, the Air Force has lost equipment, aircraft, and human lives because of accidents. Extensive investigations of accidents reveal their true causes. Knowing the true causes helps us to prevent similar accidents.

The United States Government became involved out of concern for its citizens, and Congress passed the Occupational Safety and Health Act, Public Law 91-596, effective 21 April 1971.

056. Identify governing safety directives, the title of each, responsibilities assigned, and their location.

Directives. The Occupational Safety and Health Act (OSHA) directs the Department of Labor to develop and enforce standards to "ensure safe and healthful working conditions" for all employees. OSHA also has provisions that apply to all Federal agencies. On 28 September 1974, the President issued Executive Order 11807, which directs Federal agencies to set up and use effective occupational safety and health programs.

AFR 127-12, Air Force Occupational Safety and Health Program. This regulation establishes the Air Force policy and designates responsibilities for the management of the Air Force Occupational Safety and Health (AFOSH) standards. The AFOSH standards are based on the OSHA standards. AFR 127-12 requires that all Air Force military personnel and civilian employees know about AFOSH standards and other Air Force safety, fire prevention, and occupational health guidance. You must know your responsibilities for the AFOSH Program, as well as your supervisor's which include hazard reporting and hazard abatement. Air Force Regulation 127-12 requires your boss to have all applicable standards and guidance available for your use, but the greatest responsibility is yours. You need to know where to find these AFOSH standards, know what they contain, and know how to use the information in them. The directives you must know and a brief description of each are listed below. These will be explained in more detail later in this chapter.

AFOSH Standard 127-31, Personal Protective Clothing and Equipment. This standard applies to occupational protection against biological, chemical, or physical hazards and sets the standards for the protective equipment. This standard describes the protection required to adequately protect your eyes, face, head, feet, body, and hands. It also describes protective devices for electrical workers, but it does not include normal work or seasonal clothing.

AFOSH Standard 127-9, Manually Propelled and Self-Propelled Mobile Work Platforms and Scaffolds (Towers). This standard gives you information about the maintenance stands that you have to use to do your job. It identifies hazards and tells you how to use stands safely.

AFOSH Standard 127-1, Walking Surfaces. This standard identifies walking surfaces as the source of many injury and property damage mishaps (accidents). These relatively safe areas become hazardous because people fail to correct known deficiencies. We recommend that you read this one and then look around your work area, office, and home. Is there anything there, or a condition which could cause someone to trip and fall or twist an ankle?

AFOSH Standard 161-6, General Sanitation. This standard states that all places of employment, including outside areas, should be kept as clean as the nature of the work allows, but must be kept free and clear of debris, trash, scrap, spills, or other extraneous materials that could create a health hazard or could cause an accident

In other words, this standard covers general housekeeping procedures.

AFR 161-35, Hazardous Noise Exposure. This regulation provides guidance on ear protection, directs the use of ear protection devices, and sets up the Hearing Conservation Program. As long as you are working on the flight line around operating jet engines, you should be enrolled in the Hearing Conservation Program. A copy of this regulation will be found in your unit orderly room and at the base hospital. Your supervisor is responsible for enrolling you in the program. Under this program, your hearing will be tested periodically so any hearing loss can be detected early enough to prevent any serious damage.

Finally, we come to AFR 127-101, *Ground Accident Prevention Handbook.* This has been the safety bible of the Air Force and is still a very important regulation that you need to be familiar with. It augments, clarifies, and supports other Air Force publications. The requirements in this regulation are consistent with the standards set up under the Occupational Safety and Health Act. It covers all of the safety subjects which we will be discussing later in this chapter.

TO 00-25-234, General Shop Practice Requirements for the Repair, Maintenance, and Test of Electronic Equipment. This technical order establishes basic, general, uniform specifications for the repair, maintenance, and test of electronic equipment. It includes such subjects as soldering, wiring repair, and substitution of parts to provide safe reliable equipment.

AFR 66-33, Preventing Foreign Object Damage (FOD) to Aircraft, Missiles, or Drones. Nuts, bolts, screws, safety wire, pencils, tools, ear protectors, rocks, etc., are all classified as foreign objects. They are commonly referred to as FOD when they are found uncontrolled on the flight line. AFR 66-33 sets up the program for preventing foreign objects from getting into operating jet engines. This regulation too, will be found in your unit orderly room.

Exercises (056):

1. Match the safety directive numbers in column B with the subject matter in column A and write in the title of each directive.

Column A

___ (1) Air Force safety.

___ (2) Accident prevention.

___ (3) Hearing protection.

(4) Maintenance stands.

___ (5) Maintenance practices.

___ (6) Industrial safety.

___ (7) Foreign objects damage.

___ (8) Housekeeping.

___ (9) Protective equipment.

Column B

a. AFR 161-35.
b. AFOSH Standard 127-9.
c. OSHA standards.
d. AFOSH Standard 127-12.
e. AFR 127-101.
f. TO 00-25-234.
g. AFOSH Standard 161-6.
h. AFR 35-18.
i. TO 00-20-2-10.
j. AFOSH Standard 127-4.
k. AFR 66-33.
l. AFOSH Standard 127-31.

2. What AFOSH standard covers the condition of hallways, aisles and other pedestrian pathways?

3. What Air Force regulation identifies your responsibilities, as well as your supervisor's responsibilities?

057. Determine responsibilities regarding safety programs.

Responsibilities. Any safety program is only as good and effective as the people supporting, administering, and controlling it. Support from everyone involved and affected by it is absolutely necessary. Concern for you and your personal safety is the objective of our safety programs. We, in the Air Force, have some good ideas and programs to insure your safety and well-being, but, as stated earlier, the greatest responsibility is yours. The Air Force, as your employer, has the responsibility to maintain current and effective safety programs and to research and keep you informed of all developments and conditions which could affect you. Your supervisors are key links in keeping you informed. They must keep all job-related information available for you to help yourself, and they must teach you to do your job safely. They must enroll you in occupational health maintenance programs, such as the Hearing Conservation Program, and annual physical examination programs if you work around hazardous noises, chemicals, or fuels. They must provide you with protective equipment, such as ear protectors, goggles, gloves, hard-toe shoes, etc. They are required to enforce your use of that equipment. Again, the greatest responsibility is yours. You need to find those directives which apply to your job, you need to read them—you need to use them. It is your responsibility to use the equipment provided for you and maintain it in good condition. It is really up to you to protect yourself.

Exercises (057):

Identify each true statement and explain why the others are false.

___ 1. The orderly room selects the personnel who enroll in the Hearing Conservation Program.

___ 2. Each individual who works around hazardous chemicals must schedule himself or herself for annual physicals.

___ 3. Each individual must keep safety directives related to his or her job.

___ 4. Each individual must maintain all required protective equipment in good condition.

___ 5. Enforcing safety directives is the responsibility of the Safety Office.

___ 6. Administering the Foreign Object Damage Program is the responsibility of the unit orderly room.

___ 7. Your supervisor should keep you informed of all developments and conditions which could affect your safety and well-being.

___ 8. The greatest responsibility for your personal safety belongs to your supervisor.

058. Explain how basic principles of safety relate to the objectives of specific safety programs.

Preventing Accidents. Accidents do not just happen without cause. The identification, isolation, and control of the root source is the basis of all accident prevention programs. Even the effects of the elements of nature can be controlled to some extent. For sure, the elements themselves cannot be controlled, but the effects of them can be minimized. For example, aircraft can be tied down with hatches closed and otherwise secured when strong winds are expected. Accidents caused by nature are estimated as 2 percent of all accidents and are classified under the term "natural phenomena."

Many preventable accidents can be traced to the background and the environment of the individuals involved. These tendencies reveal themselves in personal characteristics that allow an individual to perform an unsafe act or tolerate an unsafe condition that could result in an accident. These attitudes and characteristics result in loss of capability to do the job, property damage, injury, and loss of lives. Yes, it is extremely difficult to detect and eliminate such characteristics as inattentiveness, excitability, impatience, and stubbornness. On the other hand, a relatively simple and effective means of accident prevention is to eliminate unsafe acts and conditions.

All unsafe acts and conditions should be considered as direct causes of accidents. When these direct causes are removed, the sequence is interrupted, and an accident cannot happen. Fortunately, we can usually anticipate, readily identify, and immediately eliminate these unsafe acts and conditions. With this in mind, positive practical accident prevention measures are outlined in the AFOSH standards, AFR 127-101, *Ground Accident Prevention Handbook,* and applicable TOs to prevent or eliminate known direct causes. Good safety training is the most effective way of counteracting the characteristics of stubbornness, impatience, excitability, and inattentiveness, thus reducing the element of "human error." Every safety program is based on one or more of the principles of safety (or accident prevention).

Safety Training. This is a special type of training designed to prepare you and all other airmen to do your jobs safely with minimum supervision. To begin with, you need to receive specific instructions about your job, so that you are fully aware of the dangers involved and the safety practices required to offset them. We feel that when we teach you the right way to do a job, we have also taught you the safe way. When this is done, you are a safe and efficient employee.

This training should be both initial—i.e., when a new arrival enters the shop—and recurring—the latter for reinforcement and to meet operational changes.

The most frequently used methods of teaching safety are personal interviews by the shop chief and weekly safety briefings given by the shop chief. The weekly safety briefings should emphasize your work center, shop, or job high-hazard areas; i.e., working in fuel tanks, on the top of aircraft, around intakes and exhaust, around high pressure hydraulic lines, and around hydraulically operated moveable surfaces. These briefings may include off-duty safety items, such as water, sports, driving, and household safety. Remember, too, that for safety training to be most effective—it should be first, it should be repeated, and it should *not* be buried in the middle of all of the other instructions people receive.

Important steps in training are:

Analyze the job. Break down and examine, in detail, each job where training is given. Designate specific dangers.

Establish safe practices and procedures. Where you can, eliminate hazards, develop safe practices, set up safe procedures, and provide protection from any remaining hazards.

Analyze the individual. Study and evaluate individuals being trained with reference to their personal qualifications and characteristics. Watch them as they do their jobs and provide additional or special training as necessary.

Plan the training. Develop and follow a plan of instruction for the worker. It will help to maintain the worker's interest. It emphasizes the importance you place on safe work habits and practices.

Exercises (058):

1. Name the classification given to accidents caused by such conditions as lightning, storms, and floods.

2. Identify the causes of accidents that are the easiest to eliminate.

3. Name four personal characteristics that are difficult to detect and counteract.

4. What is considered the best way of reducing human error as a cause of accidents?

5. Briefly explain why the supervisor's orientation of each new arrival to the shop is a key step in safety training.

6. Describe, and give the frequency of the type of safety training that deals with occupational high-risk duties.

7. The Foreign Object Damage Program, which is designed to prevent damage to jet engines, is based upon which safety concept?

8. What three concepts form the basis of accident prevention programs?

3-2. Fire Safety

One type of safety training emphasized throughout the Air Force is fire extinguisher training. You need to be familiar with the four general classes of fires, the fuels for each class, and which type of extinguisher to use on different fires.

If you remove the causes of an accident, you avoid an accident. The same theory applies here. If either fuel, heat, or oxygen is missing, a fire cannot start. When either of them is removed, the fire will go out. Let's discuss fires, their classes, and methods of controlling them.

059. Define and classify fires; identify methods of control and typical fuels for each class.

Classification of Fires. Fire is a chemical reaction between a combustible material and oxygen. Three things must be present at the same time to produce a fire—fuel, heat, and oxygen.

Fire extinguishers, which are usually hand operated and portable, are designed to remove one or more of the three elements of combustion. Fire extinguishers are intended only for emergency use during the initial stages of a fire.

Fires are grouped into four general classes, each of which can be extinguished by a particular action or agent. All fire extinguishing agents cannot be used on all types of fires; therefore, we classify them so we can determine and use the best agent to fight a particular type of fire.

Wood, paper, or rags. We have found that water, or chemicals in water solutions, are the best to use to control and extinguish fires involving wood, paper, or rags. Water acts to cool the combustibles, thus eliminating the heat required for combustion. Fires involving wood, paper, or rags are of class A.

Flammable liquids. Fires that occur in flammable liquids, such as fuels, oils, solvents, or greases are of class B. The agents required for extinguishing fires of this class are those which will dilute or eliminate air by blanketing, thereby creating a smothering effect. NOTE: Water must not be used because these substances will float and cause the fire to spread.

Electrical. Fires occurring in electrical equipment are usually fueled by insulating materials or plastic compounds. These materials will usually smolder or smoke rather than produce an open flame. The extinguishing agents designed for this class of fire *do not* conduct electricity but work by smothering the fire. These fires are of class C.

Combustible metals. Some metals can burn. Fires that occur in combustible metals, such as magnesium, potassium, powdered aluminum, zinc, or sodium are of class D. Dry powder extinguishers must be used on all class D fires.

Exercises (059):

1. Define fire.

2. How many classes of fires are there?

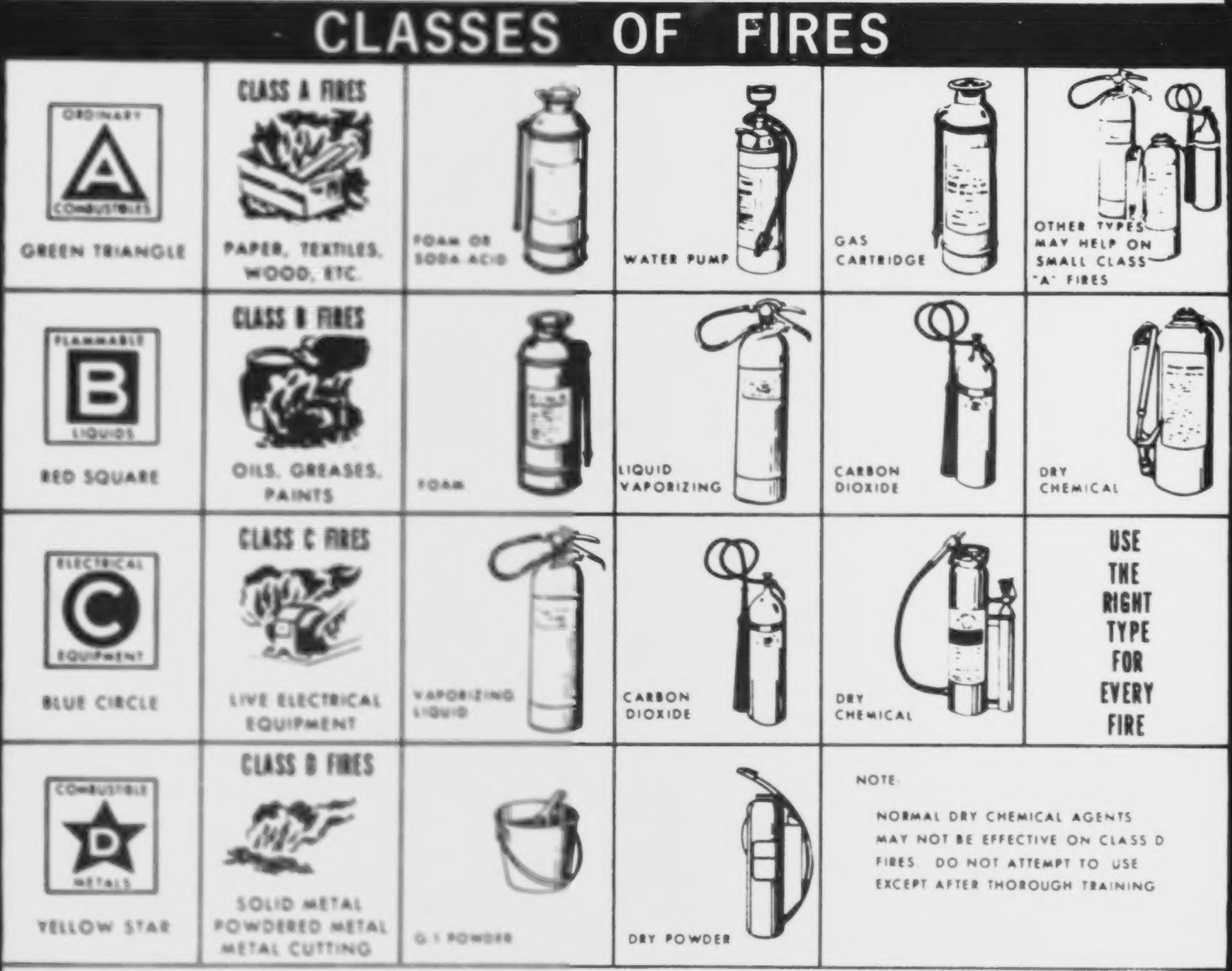

CLASSES OF FIRES
ORDINARY
A
COMBUSTIBLES
GREEN TRIANGLE
CLASS A FIRES
PAPER, TEXTILES, WOOD, ETC.
FOAM OR SODA ACID
WATER PUMP
GAS CARTRIDGE
OTHER TYPES MAY HELP ON SMALL CLASS "A" FIRES
FLAMMABLE
B
LIQUIDS
RED SQUARE
CLASS B FIRES
OILS, GREASES, PAINTS
FOAM
LIQUID VAPORIZING
CARBON DIOXIDE
DRY CHEMICAL
ELECTRICAL
C
EQUIPMENT
BLUE CIRCLE
CLASS C FIRES
LIVE ELECTRICAL EQUIPMENT
VAPORIZING LIQUID
CARBON DIOXIDE
DRY CHEMICAL
USE THE RIGHT TYPE FOR EVERY FIRE
COMBUSTIBLE
D
METALS
YELLOW STAR
CLASS D FIRES
SOLID METAL
POWDERED METAL
METAL CUTTING
G-1 POWDER
DRY POWDER
NOTE:
NORMAL DRY CHEMICAL AGENTS MAY NOT BE EFFECTIVE ON CLASS D FIRES. DO NOT ATTEMPT TO USE EXCEPT AFTER THOROUGH TRAINING

Figure 3-1. Classes of fires

3. Name the classifications of fires and list the fuels for each.

060. Associate fire extinguisher types with classes of fires.

Use of Extinguishers. In order to extinguish a fire, you need to remove one of the three fire-producing factors. You must starve, smother, or cool a fire to extinguish it. You starve a fire by cutting off the supply of fuel. You smother a fire when you remove oxygen (air) from it. The use of foam, carbon dioxide (CO_2), or sand will produce a smothering effect. You cool a fire when you remove heat from it, normally by putting water on it. Some water extinguishers use a carbon dioxide cartridge to provide extra pressure.

NOTE: Remember to use water on class A fires only; water will make a petroleum fire spread; water is a conductor of electricity, and you could be electrocuted.

CAUTION: Always use a fire extinguisher upwind from the fire. Some of the extinguishing agents are extremely toxic, and could severely, even fatally, hurt you.

Figure 3-1 shows the common types of fire extinguishers. You may use some of them on more than one class of fire. Therefore, you should study figure 3-1 carefully. Learn which extinguishers you can safely use on each type of fire.

Foam is often used on petroleum fires because it is lighter than petroleum products. This characteristic causes the foam to float on top of the fuel and smothers the fire by cutting off the supply of oxygen. You should never put foam on electrical equipment because the water in the foam conducts electricity.

To use a foam extinguisher, grasp the hose, turn the extinguisher upside down, and direct the foam against a wall, the side of the tank, or on the ground so the foam will gently spread back over the burning substance. You may also throw the stream of foam high, so that it arches onto the surface of the burning substance and gently spreads. Remember, fire extinguishers are for emergency use only. Once you invert a foam extinguisher, it cannot be stopped. Even if you turn the extinguisher right side up, the foam will flow until the extinguisher is empty.

Dry chemical extinguishers (not to be confused with dry powder) are good for putting out fuel fires at domes of tank cars or tank trucks. These dry chemical extinguishers contain bicarbonate of soda, which is released when a turn of a handwheel punctures an inner cartridge of carbon dioxide or nitrogen. This action releases both a smothering gas on the fire and a dry chemical which shields you from the heat. Dry chemical is also excellent for putting out electrical fires.

Carbon dioxide is a common agent used in fire extinguishers. It is a gas which is about $1^1/_2$ times heavier than air. When CO_2 is discharged, its vapors look like snow. It acts both to smother and to cool. When you use the CO_2 extinguisher, grasp the carrying handle and place the extinguisher on its base in the upright position. CAUTION: Keep your hand off the CO_2 extinguisher discharge horn. The horn becomes extremely cold and your hand may get frostbitten. Grasp the discharge hose by its wooden or rubber handle to remove the horn from its bracket. Turn the valve clockwise, or, if a grip-type valve is used, squeeze the handle. Hold the discharge hose by the wooden or rubber handle and direct the CO_2 toward the base of the flame and slowly work from side to side. Advance the discharge slowly across the burned area as the flame is extinguished. Don't direct the CO_2 too high or haphazardly over the flame. You could cause the flame to flare back at you.

Sand (or dirt) can be used to put out small petroleum fires if you don't have a better extinguisher. The sand creates a blanket that smothers the blaze.

Dry powder is used to smother fires that are found on combustible metals, such as magnesium. Do not confuse this with dry chemicals.

Another agent used on combustible metals is G-1 powder. This is a graphite powder which is scooped from a pail or bucket. It, too, is used to smother the flames.

In conclusion, remember that different extinguishers use different elements (agents) to control fires. Always use a fire extinguisher from a position where you can take advantage of the wind; that is, upwind of the fire so that the flames will be blown away from you.

Exercises (060):

1. Match each type of fire extinguisher in column B with the classes of fires on which it can be used in column A.

Column A	*Column B*
____ (1) Dry chemical.	a. Class A fires.
____ (2) Water pump.	b. Class B fires.
____ (3) Carbon dioxide.	c. Class C fires.
____ (4) Foam.	d. Class D fires.
____ (5) Gas cartridge.	
____ (6) Soda-acid.	
____ (7) Vaporizing liquid.	
____ (8) Dry powder.	

2. Identify each true statement and explain why the others are false.

____ a. A fire is starved when the oxygen has been removed.

____ b. A water pump fire extinguisher is generally used to smother a fire.

____ c. A carbon dioxide fire extinguisher cools a fire.

____ d. A fire is starved when the fuel source is cut off.

3. Identify a limiting factor of each of the following types of fire extinguishers.
   a. Carbon dioxide.

   b. Foam.

   c. Water.

3-3. Safety Hazards in Instrument Maintenance Shops

A good part of your work is done in the shop. It includes bench checking and repairing components, repairing test equipment, manufacturing hoses or cable assemblies, or loading or unloading equipment or parts. This section will acquaint you with the dangers associated with poor housekeeping practices. It also provides a short review of some of the areas already covered.

061. Explain the hazards in storage of solvents and lubricants, and specify the safety precautions they require.

Hazards of Solvents and Lubricants. The hazards inherent in handling and being exposed to solvents and lubricants are many. For example, damage to vital organs may be caused by absorption of the toxic agent into the bloodstream through prolonged breathing of vapors or by direct skin contact. Some problems which can result are liver or kidney damage, respiratory ailments, or central nervous system depressions. Additionally, acute or chronic skin disorders may be caused, depending upon the type of agent used. Some solvents remove natural oils and fats and cause the skin surface to become dry, hard, and broken. A break in the skin may cause bacterial infection.

There are a number of other hazards associated with solvents and lubricants during their storage and use. Some of these are classified as health hazards and others as accident causes.

Mishandling of solvents and lubricants may also result in fire or explosion. This is particularly true in the case of lubricants or when the wrong type of solvent is used. For example, some solvents will melt plastic or corrode metals; many lubricants will not mix with other lubricants; and many lubricants are not suitable for use in electrical equipment, because they conduct electricity and cause system failures because of shorting. Some silicone products provide good insulation for electrical circuits, some do not, and some do not mix well with hydraulic fluid. Loss of a hydraulic system, flight control system or even an indicating system because of improper lubrication, could result in the loss of an aircraft and human lives.

Storage precautions. Solvents and lubricants can be stored so that health and accident hazards are minimized. Whatever the type of solvent or lubricant used, store only as much as you need until you get your next requisition. Use only approved metal containers and store them in areas outside of the building, where they will not be subjected to excessive heat, sparks, or flame. Some solvents, while not actually volatile, will build up extreme pressure inside a sealed container when subjected to heat. This may cause a container to rupture, spraying or splashing the contents on personnel or equipment. This is particularly true of material contained in aerosol spray cans. In addition, lubricants leaking from a faulty or unsealed container may readily ignite when in an area where they are exposed to sparks or open flame. Always use care in the manner and selection of the area in which you store solvents and lubricants.

Safety measures. As we mentioned previously, only approved and authorized solvents are used for cleaning equipment. Under most circumstances, solvents having suitable cleaning characteristics may already be selected for use in your maintenance area. To get the job done, the solvent should clean and degrease thoroughly, leave little or no residue, and cause no deterioration of components or insulation. To get the job done SAFELY, the solvent must also be nonvolatile, nonflammable, and as nontoxic as possible. Normally, solvents that are flammable or volatile will NOT be used.

When opening a solvent container, be careful to avoid spilling any of the solvent onto your clothing or skin. Also, be careful to avoid splashing or spraying the solvent into your eyes or another person's eyes.

Always follow the instructions for the solvent you are using. Do not mix solvents, as some combinations will react chemically to produce a deadly or explosive gas.

Avoid breathing the vapors or fumes of solvents; especially avoid any prolonged exposure. Use solvents in well-ventilated areas so that there is no concentration of the fumes. Some type of exhaust ventilation is necessary if solvents are used on a continuing basis. A work area where a cleaning solvent is used must be inspected periodically by a bioenvironmental engineer or qualified medical specialist to insure that ventilation is adequate. In addition, personnel who are exposed to certain types of solvents on a continuing basis are required to have a periodic examination. This need is determined by base medical personnel according to the type of solvent used and the frequency of exposure. If your work area has a cleaning facility using bulk amounts of solvent, base medical personnel may be contacted to determine whether or not such a physical examination is necessary.

If aerosol solvents are used, follow the directions carefully. Make sure that you spray the solvent only where needed and only in the amount necessary. Make sure coworkers are not contacted by the solvent. When using bulk solvents, as in open containers or pans for bathing parts and assemblies, wear protective gloves.

You will use and encounter many types of solvents and lubricants in your daily job. AFR 127-101 provides detailed instructions on the hazards, use, and storage of solvents and lubricants.

You need to know how to dispose of hazardous solvents and lubricants. They should not be thrown into the trash, washed down the drains, or poured out on the ground. If your supervisor does not already have disposition instructions for the materials you are using, then you should contact your base bioenvironmental engineer at the hospital to determine how to dispose of unuseable materials safely.

Exercises (061):

1. Explain how solvents and lubricants can damage vital organs in your body.

2. Give two ways in which toxic substances may be absorbed into the bloodstream.

3. What general precautions should be used in storing solvents and lubricants?

4. Describe briefly the possible consequences of storing a sealed container of nonflammable solvent in a furnace room.

5. Describe briefly the possible consequences of storing flammable solvents near a water heater.

6. Why should you use lubricants designed for electrical equipment on electrical equipment?

7. What safety characteristics should you look for when selecting solvents for use where a specific solvent has not been designated?

8. List three ways you should NOT dispose of solvents and lubricants.

062. Specify hazards present and precautions required when working with electricity.

Hazards of Electricity. The wide use of electronic equipment in almost every Air Force maintenance area exposes personnel to many accompanying dangers. Poor judgment in the use and maintenance of electronic equipment and electrically powered tools is the major cause of injuries and equipment damage. Instrument personnel are constantly exposed to the dangers of severe electrical shock and burns that result from contact with "hot" circuits. Short circuits, overloading, accidental grounding, poor electrical contacts, and misuse of equipment are all causes of the major accidents involving electricity. By observing the safety precautions discussed here, you can minimize the danger of electrical shock.

Precautions. Almost all electronic equipment has dangerous voltages. Before working on such equipment, be sure that it is turned off and that it can't be turned on accidentally.

Don't wear metallic objects, such as rings, identification tags, medals, wristwatches, glasses with metal rims, or bracelets, when working near any electrical potential.

Don't bring metallic measuring rules, metal-cased objects, or metal tools near energized electrical circuits.

Don't depend upon friction or rubber tape on the handles of tools to prevent electrical shock. Avoid using screwdrivers with wooden handles, since the wood can absorb moisture. Always use screwdrivers with rubber or plastic handles when working around electricity.

Keep the area surrounding high-voltage equipment clear of all obstructions, such as tools, toolboxes, and other foreign objects.

Take your coffee breaks in the break area and keep conductive liquids away from electrical equipment.

Be sure to learn the location of the main power switch. If someone contacts a live circuit, or if something in the equipment starts to smoke, PULL THE SWITCH! But never close a switch unless you know what is connected to the circuit involved.

Never hold a meter in your hand when you make a voltage or current measurement. Always place the meter in position, put your left hand behind you as you attach the meter leads to the circuit being tested, and stand at a safe distance to read the meter.

Don't work alone on high-voltage equipment. Air Force Regulation 127-101 and the AFOSH standards and technical orders require a qualified safety observer to be present. Another specialist or technician will do, but the observer must know how to turn off the equipment and be capable of applying emergency first aid, including cardiopulmonary resuscitation (CPR).

Exercises (062):

1. State the major cause of accidents and injury when working with electronic equipment.

2. List five hazards responsible for accidents involving electricity.

3. State the first precaution you should take before working on electronic equipment.

4. Give the precaution required before working near an

electrical potential as regards to any metallic objects you may be wearing.

5. When working on electronic equipment, why should wooden-handled screwdrivers be avoided?

6. State the required precautions regarding main power switches.

7. How should a voltmeter be handled when it is in use?

8. List the qualifications of the safety observer for high-voltage maintenance.

063. Identify the dangers of compressed air.

Compressed Air and Its Hazards. Although compressed air is used in many different ground maintenance operations daily, few persons realize the dangers associated with its handling and use. Serious injuries have been caused by using compressed air to blow dirt or dust from work clothes or by using it to clean up filings, chips, and shavings from repair jobs. Air pressure that is strong enough to clean dust or dirt is also strong enough to injure a person's eyes and ears and to penetrate the body. Air blown into a small cut can inflate an arm or leg just like a balloon. Pressures as low as 10 to 15 pounds per square inch (psi) have been known to cause serious injuries. It has been estimated that a pressure of only 4 psi will rupture the intestines. Compressed air must be handled with care. When compressed air is being used, you should be careful to keep foreign objects from entering the equipment. Not only can this damage the equipment, but personnel can be injured by small objects blown out of nozzle openings. If a hose is not attached or held, it could whip around like a snake when the air pressure is turned on and strike personnel or equipment, causing extreme damage or serious injury. AFR 127-101 requires all air pressure used for cleaning to be regulated by pressure regulators. Prior to use, the air lines and connections should be inspected for defects.

Exercises (063):

1. List three hazards associated with using compressed air.

2. Why should you avoid using compressed air to remove dust or dirt from your clothing?

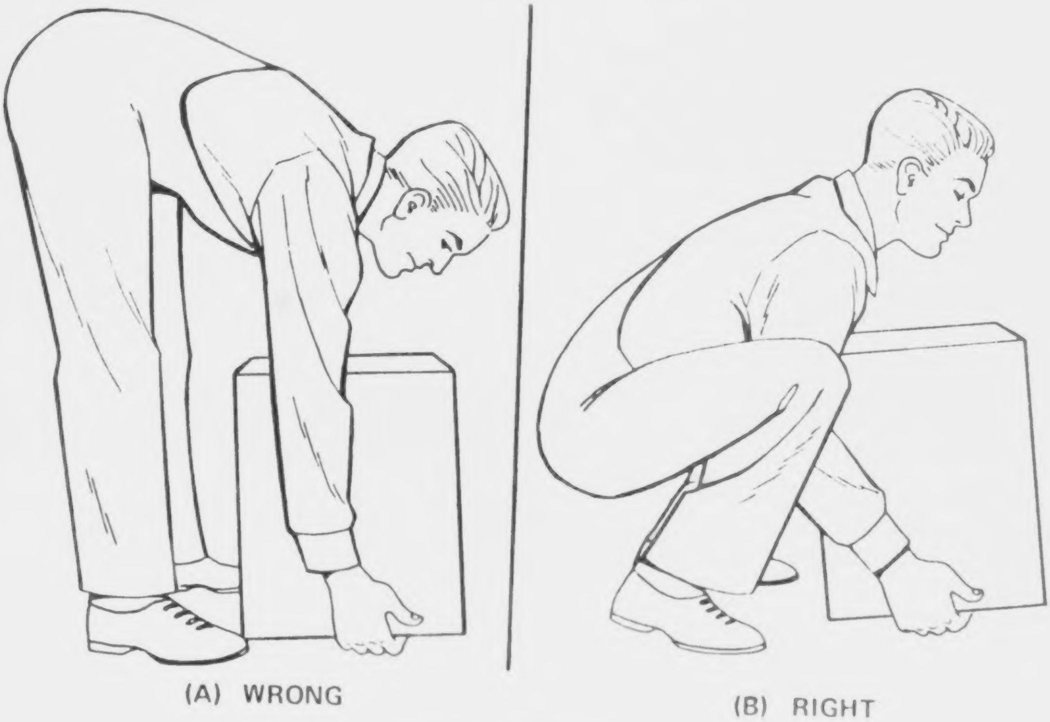


Figure 3-2. Lifting posture.

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064. Specify the hazards present, and the precautions and considerations that should be taken when lifting.

Lifting. Although lifting may seem a very menial part of your overall job, it is important because of the hazards it presents. In recent years, the injury problem in the Air Force caused by the manual handling of equipment has become acute. This increase is almost entirely because of poor handling practices. Now, let's review some of the commonsense precautions which you should follow.

When you lift an object, grasp it so that you can control it if it becomes unbalanced. If the object is to be lifted from a level lower than your waist, you should lift it as demonstrated in figure 3-2. Assume a squatting position, with your back straight, and allow your legs to exert the primary lifting force. Use the reverse of this method to set the object down. Be particularly careful when releasing the object in order to prevent injury to your fingers, hands, and feet.

Personnel considerations. Physical differences in personnel is an important factor in the unloading process. Safe lifting limits vary for all individuals; however, a good rule of thumb is 50 pounds for male personnel and 25 pounds for female personnel.

If you have an object that is too heavy for you to handle safely, be sure to ask for help. Select someone who is close to your height so that the load may be carried evenly. Before you start carrying the object, decide on the route you are going to take and arrange an emergency signal, should it be necessary for either of you to release the load suddenly. As you begin to walk, stay in step. This will make it easier for both of you to coordinate your movements and to carry the object safely and smoothly.

If the load is too heavy or bulky for two people to carry safely, use a handtruck or forklift. When these mechanical aids are used properly, they will simplify handling and reduce the hazards connected with moving large objects. This subject, too, is covered in AFR 127-101.

Exercises (064):

1. You have been instructed to unload equipment from a truck. What are the initial factors you should consider?

2. What position should you assume to lift an object from a level lower than your waist?

065. Identify responsibilities, dangers, areas of concern, and safety precautions involving good housekeeping procedures.

Housekeeping Procedures. The work center supervisor has primary responsibility for seeing that good housekeeping procedures are followed and unsafe conditions are eliminated. Of equal importance, however, is the worker's adherence to good housekeeping practices. So, whether you are assigned as a supervisor (a distinct future possibility) or as a worker, you must learn more about this subject and follow the procedures which help to eliminate accidents.

AFR 127-101 and the AFOSH standards provide more in-depth information and outline specific responsibilities regarding housekeeping practices. You are encouraged to look up the answers to questions you may have about practices in your shop.

Indoor Housekeeping. The principal precautions which must be observed in interior housekeeping include the arrangement of work areas and lighting; tool and materials storage; and the removal of scrap, waste, and spills.

Arrangement and lighting. The indoor arrangement of facilities where you work is of great importance. When a work area is designed, it should be laid out to simplify the practice of good housekeeping. This allows orderly operation and helps to avoid congestion in work areas. Good layout of installations can best be achieved in the planning stages, but your interest and suggestions after the fact can also help insure a safe work center.

Badly lighted areas contribute to poor housekeeping practices and accident possibilities. Insure that all workbenches, aisles, stairways, and rooms remain adequately lighted during use. If an area is not properly lighted, either correct it yourself or notify your supervisor, so that the situation can be corrected. All fluorescent lighting fixtures should be protected with shields or clamps to keep the tubes from falling.

Storage and disposal. The residue of work is often in the form of waste paper, wood or metal scraps, old components, or dirty rags. Do not allow these items to accumulate in your work area. Instead, find suitable containers to store them in until they can be disposed of properly. Use separate containers for different materials, such as metal, wood, paper, or cigarette butts. NEVER put smoking materials or cigarette butts in any container unless it is designed and marked specifically for that purpose. Use clearly marked metal containers with self-closing lids to dispose of combustible wastes, rags, and other flammable materials. Do not allow scraps and waste to accumulate and unnecessarily clutter up your work area. Dispose of them daily or move them to a safe location.

Oil, water, and other such substances on floors can cause slips and falls. Clean up this type of mess immediately to keep it from causing an accident involving yourself or a coworker. If flammable liquids are spilled, make sure that you thoroughly remove the spill by using noncombustible absorbent materials.

Do not leave tools and materials on equipment racks, desks, or workbenches, where they might be knocked off or fall. Use suitable toolboxes or racks for safe tool storage. A good rule is: "A place for every tool and every tool in its place." Store paper, books, shoeshine kits, and all other materials in their proper place. If you must temporarily allow a potentially dangerous condition to exist, post warning signs or otherwise warn others so that they will be aware of the hazard.

Outdoor Housekeeping. Good housekeeping is as important outdoors as indoors. The storage of materials and the neatness of roads and grounds cannot be overemphasized. Accidents occur outside of your work area as frequently as on the job.

Storage. Materials should never be stored under outside stairways. Boards stacked under an open stairway, for example, may slip from the stack, project through an open step or out to the side of the stairway, thus tripping someone. Also, this creates a potential fire hazard. If the stairs catch fire it eliminates a path for escape. Be careful not to store materials where they will block doors or exits. In addition to the danger of causing a fall, a blocked door or exit could cause grave personal injury in case of emergency evacuation of a building. Do not store flammable materials, such as paint or thinners, next to buildings. Preferably, these should be in closed metal containers, located in a shelter detached from the building. Warning signs must be posted so that personnel are aware of areas where flammable materials are stored. Do not store any type of materials on the roof of a building.

Roads and grounds. Do not allow grass or weeds to grow excessively near buildings or access areas. Such growths greatly increase the possibility of fire. Pick up objects on the ground which could cause personal injury or equipment damage during mowing or cleanup operations.

Good outside lighting is an important factor in housekeeping. Roads, walks, stairways, and grounds must be kept well lighted so that all permanent obstructions may be avoided and temporarily out-of-place objects may be removed.

Exercises (065):

1. Who is held primarily responsible for unsafe conditions caused by poor housekeeping practices?

2. What is the best way to insure good arrangement of work areas?

3. Give the method of storing scraps and waste temporarily.

4. If a potentially dangerous condition must remain temporarily, what action should you take?

5. Why should you avoid storing materials under stairs?

6. Where should flammable materials such as lubricants, solvents, and thinners be stored?

3-4. Flight Line Safety

Your shop area is a very safe place compared to the flight line, but the flight line is where most of your work will be done over the next few years. All of the general safety hazards and shop hazards will be encountered on the flight line, as well as many other hazards peculiar to flight-line environment.

066. List radiation hazards, and specify protective measures and warning devices as relating to aircraft maintenance shops.

Radiation. While working on the flight line or in the shop, you can be exposed to radiation. This may be in the form of radiated energy—radio frequency (RF) radiation from an aircraft radar system or from parts, materials, or test equipment containing radioisotopes. Examples of such equipment are the nucleonic oil quantity system components used on some aircraft and vacuum or gas-filled tubes stored in bench stocks and photometers, which may be found in some shops.

In any case, clearly understandable markings must be used to warn personnel of the danger. The standard marking placard used to identify a radiation source is shown in figure 3-3. The background is yellow, the symbol is magenta, and the lettering is black. Packages, containers, and work and storage areas must be marked with the standard labels or placards so they are visible from all directions.

AFR 127-101 provides guidance on radioactive material. It states that radioactive tubes should be stored, handled, and disposed of in accordance with TO 00-110N-7. Although most of these tubes do not present a hazard of high radiation levels, a potential hazard does exist, since the tubes could be broken and radioactive material might enter the body by way of cuts, ingestion, or inhalation. Like toxic solvents and lubricants, they must be disposed of in such a way to insure that unwary personnel do not inadvertently break the tubes and contact the hazardous material.

Labels or placards are to be removed when the container or area no longer contains the radioactive source.

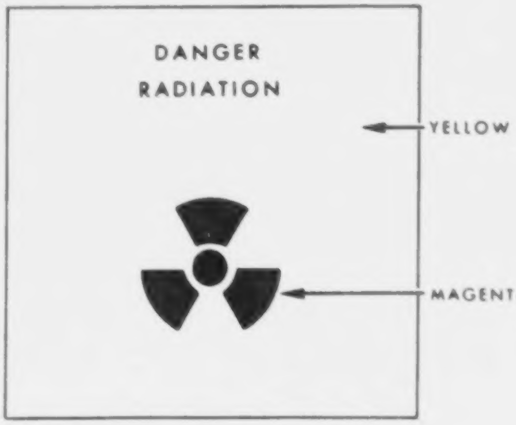


Figure 3-3. Radiation placard

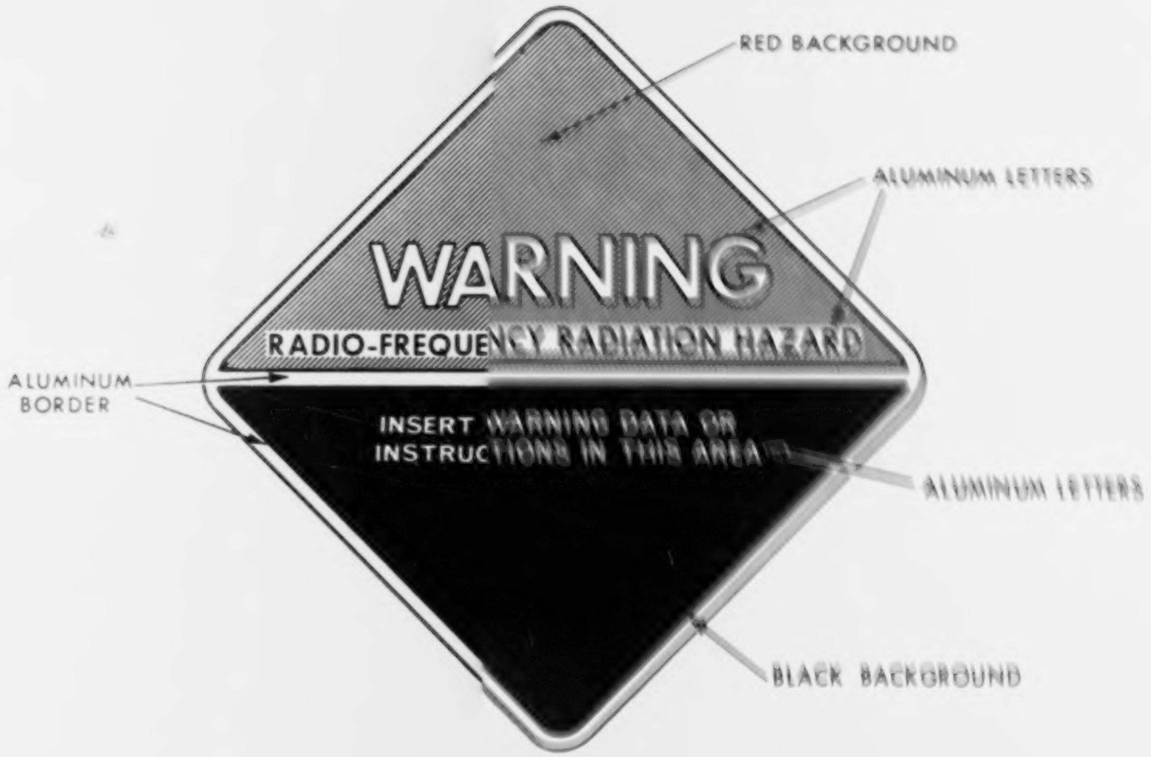


Figure 3-4. Radio-frequency radiation warning sign.

Radio Frequency Radiation. As with nuclear radiation, radio frequency (RF) transmissions are a danger that we cannot see, hear, or feel. It is also referred to as electromagnetic radiation. This radiation is given off by high frequency radio transmitters, radar, or electronic countermeasure devices. The source of this hazard is often hidden behind the radome of an aircraft but can frequently be seen in the maintenance shop when the unit is being repaired and tested. The energy radiated by these transmitter antennae can cause flashbulbs to ignite and steel wool to burn. It can cause burns beneath your skin and eye cataracts. The injuries may occur before any pain is felt. When electromagnetic energy is absorbed within the body tissues, heat is produced. If the heat cannot be dissipated as fast as it is produced, the internal temperature of the body will rise. Because the internal organs are not cooled by an abundant flow of blood, they can be damaged easily by heat from excessive exposure to radiation.

Because we cannot see or hear RF radiation, all suspected or known hazardous areas will be posted with warning signs (see fig. 3-4). When these signs are posted around an aircraft or shop area, you are not to enter the field or beam of any energized antenna (see fig. 3-5).

Exercises (066):

1. List three sources of nuclear radiation found in aircraft maintenance.

2. In terms of color scheme, describe the standard warning placard for radioactive parts and materials.

3. What is the hazard associated with radioactive tubes?

4. List three sources of RF radiation.

5. Explain the principal effects of RF radiation on the human body and vital organs.

6. What protective measures are used against RF radiation?

067. Identify the hazards present in the cockpit environment, and describe the precaution that should be taken when working about the aircraft.

Cockpit Safety. The cockpits of fighter and bomber

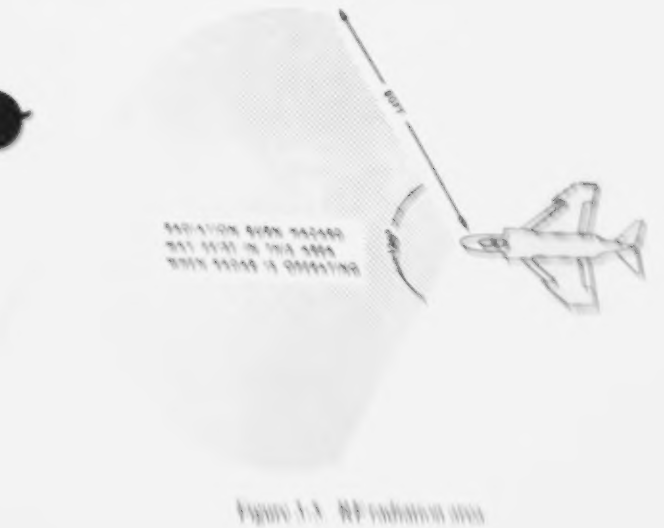


Figure 3-5. RF radiation area

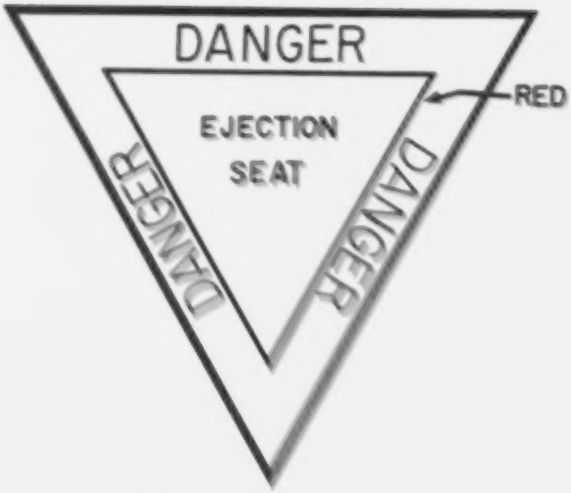


Figure 3-6. Ejection seat warning sign

aircraft have always presented a hazardous condition to maintenance personnel. The greatest hazard is because of the explosive charges which eject the canopy and seat. Accidental firing of ejection seats and canopies can result in serious personal injury and damage to the aircraft. As a safety precaution, seat and canopy ground safety pins with streamers are installed immediately after flight, and remain installed while the aircraft is on the ground. When working close to ejection seat catapults or canopy remover controls, insure that the safety pins are installed. Exercise particular care to avoid accidental arming and firing, since extreme heat or unintentional movement of the actuating mechanisms can fire the ejection seat catapult or canopy remover. You can identify the ejection seat by a warning sign, usually painted on the side of the aircraft, as shown in figure 3-6.

These systems command the same respect from maintenance personnel as does a machine gun or an aircraft cannon, since—indirectly—the catapult containing the ejection seat explosive change is capable of hurling 300 pounds at an initial rate of 60 feet per second.

Although the previous information is true regarding most of the fighters and bombers in today's Air Force, the construction of advanced aircraft presents an entirely new and different type of hazard as related to the cockpit.

Some newer aircraft have an ejectable crew module for escape purposes. The crew module forms an integrated portion of the forward fuselage. The entire module is ejected from the aircraft. Ejection is accomplished by firing shielded mild detonating cord (SMDC), which in turn fires guillotines. The guillotines sever control cables, oxygen lines, antenna leads, etc., which enter the capsule. The SMDC also fires splice plate explosive severance strip charges, which sever the module from the aircraft. The SMDC ignites the rocket motor to separate the module from the remainder of the aircraft. Several compartment covers on the module contain explosive charges. The greatest hazard resulting from inadvertent firing of the escape system is due to flying debris or pieces of metal. Compartment covers and pieces of metal from the severance strips are propelled in random directions to a distance of up to 100 feet. The second hazard results from the rocket blast when the rocket motor is ignited. The blast is directed downward and exists underneath the aircraft. Severe burns could result to anyone underneath the aircraft should the ejection system be inadvertently activated.

You should also watch out for and avoid the disease known as "switchitis." No, you won't find this word in the average dictionary. It is a flight-line term that describes people who just have to turn every switch or lever they see in order to find out what will happen. If this fits you, you may be in for an unexpected ride or the shock of your life. Look at figure 3-7 in connection with this danger, and never pull a handle or flip a switch if you do not know what the results will be. Remember, the modern aircraft cockpit is deadly in the hands of the inexperienced. The reason, of course, is that the cockpit contains controls for explosives, wingtip tanks, canopies, flaps, and landing gear controls—all of which are "killers." Also, be aware of other people working on the aircraft. This is especially important if electrical or

Figure 3-7. Switchitis

pneudraulic power is applied. If you accidentally hit the wrong switch at the wrong time, someone could be seriously hurt. So, if you ever feel "switchitis" coming on, stop what you are doing and ask someone else what "that switch" does.

Power-Actuated Systems. Aircraft with power-operated (mostly hydraulic) devices, such as flight control surfaces and landing gear, present a potential danger. If you carelessly operate any of these, you can damage equipment or seriously injure someone. These systems are designed to operate quickly and against heavy airloads. They can be quite dangerous unless all precautions are observed. Most power-actuated systems have safety locks which must be installed during ground operations. As an example, before going into a bomb bay to work, make sure that you deplete hydraulic pressure and install the safety locks and put danger tags on the controls. If someone accidentally tries to operate the system while you are working inside, the lack of hydraulic pressure and the safety locks will prevent the bomb doors from slamming shut. Don't get trapped by someone throwing levers or switches. Curiosity can be dangerous, and there is a little bit of it in everyone. When operating systems to check them out, make sure that they are clear of personnel and equipment. Have someone stand by to make sure that everyone stays clear of the danger area. By all means, don't work on a system when hydraulic pressure is applied or the system is being operated. This has probably caused more deaths and injuries than any other single operation.

The flight control surfaces, landing gear doors, bomb bay doors and cargo loading doors—just to name a few—all have sharp edges. Therefore, when working on or near these edges, be especially cautious; serious injuries have occurred when persons simply rose too quickly from kneeling down under a landing gear door or walked into sharp edges of the flight control surfaces. Wear your cap and fatigue jacket when working around these areas. They will offer you some protection.

Also, consider the hazards involved in tools and debris left in the cockpit. Obviously, loose tools and debris left here can cause serious personal injury and equipment malfunctions. For example, a wrench, screwdriver, or other debris littering a cockpit can jam a control, or it could unexpectedly come flying out and strike the pilot or the instrument panel later, when the aircraft is performing maneuvers. Therefore, when you work in an aircraft cockpit, check to be sure that you have all of your tools and equipment before you leave. You should use a locally prepared checklist of each tool and object carried in a toolbag to insure that your shop is never responsible for foreign object damage (FOD).

Exercises (067):

1. What is the greatest cockpit environmental hazard present on most fighter/bomber aircraft?

2. What precautions should you take if you are required to perform maintenance in or around the cockpit?

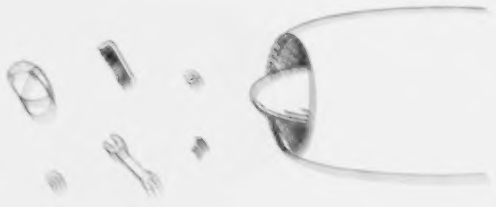

F O D CAN BE PREVENTED

Figure 3-8. FOD can be prevented.

3. Describe briefly what can happen if a tool is left in the cockpit.

4. State the precautions to be observed when you are working on power-actuated systems.

068. Define foreign object damage (FOD) and state methods of preventing FOD.

Foreign Object Damage. Foreign object damage is a common Air Force term used to describe any foreign object that doesn't belong where it is, such as nuts, bolts, washers, tools, cotter pins, safety wire, stones, or rags. Foreign object damage can and does cause damage to aircraft. It is an ever-present hazard to the operation of jet engines. Therefore, all maintenance personnel must exercise extreme care while performing maintenance in and around the aircraft, in order to prevent foreign object damage to the engines. The large size of the newer jet engines creates higher suction pressures that enable the engines to pull objects from greater distances into the engines. Therefore, it is mandatory that personnel performing maintenance on aircraft account for all tools, hardware, and components after maintenance has been accomplished or before engine runup. See figure 3-8 as it relates to FOD problems. Numerous engines have been completely demolished because someone failed to police the runup area or check the engine intakes for FOD before the engines were started.

Remember, AFR 66-33 covers the Foreign Objects

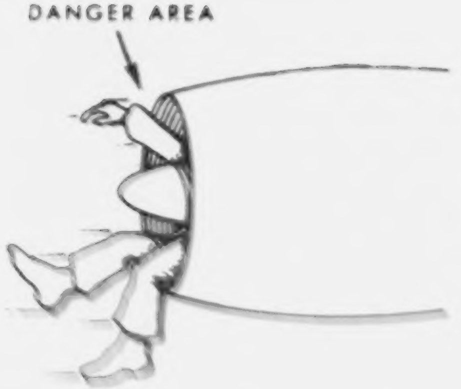


Figure 3-9. Suction effect of a jet engine.

Damage Program. All incidents caused by FOD are reportable to the major commands. This includes shorted electrical circuits because of safety wire and other conductive materials, and jammed flight controls because of lost tools and other hardware.

Small bits and pieces of FOD cost the Air Force millions of dollars every year. We must be alert to the dangers of FOD. We must clean our work areas thoroughly after every job, and do everything possible to prevent FOD.

Exercises (068):

1. State the definition of FOD.

2. List methods of reducing the danger of FOD damage.

069. List danger areas and conditions around operating aircraft engines, and cite selected hazards and safety procedures.

Jet Engine Dangers. The operation of jet engines constitutes a major source of another group of hazards that you must be aware of when working on the flight line. The major danger areas here are: (1) the intake, (2) the exhaust, (3) the turbine plane, (4) the cartridge starter, (5) the auxiliary air inlet doors, (6) the heat, and (7) the noise level.

Suction effect. The suction effect at the intake is sufficient to cause fatal injury to personnel and extensive damage to equipment. It is strong enough to pull an average size person into the intake (see fig. 3-9). A safe distance from these inlet ducts is normally 25 feet to the front and sides of the intake (see fig. 3-10). On some of the more advanced aircraft, the technical order cautions that danger exists in an area that extends to 4 feet behind the inlet when the engines are operating at high-power settings.

To aid in preventing accidents while you are around operating jet engines, remove and secure your hat, and never wear loose clothing or objects on your clothing that might come loose and be drawn into the intake. In addition, remove all objects from in front of or within the intake ducts before the engines are started.

Exhaust blasts. The heat and force of jet engine exhaust blasts are particularly hazardous to personnel. Carefully avoid the exhaust area of operating jet engines. All persons, vehicles, and aircraft are prohibited from passing behind a jet aircraft when the engines are operating. A ground crewmember is stationed outside of an operating jet aircraft to warn personnel and traffic to remain clear for a distance of approximately 200 feet to the rear of the aircraft (see fig. 3-10). The distance could vary according to the type of aircraft, but the minimum safe distance is prescribed in the applicable aircraft handbook. A blast fence is installed when there is not sufficient clearance to the rear to protect personnel and equipment. Before any jet engine is started, remove tools, spare parts, and other objects from the blast areas.

The turbine plane. There have been instances when objects rotating at tremendously high speeds have disintegrated. The turbine wheels in jet engines have failed in that way. When an object, such as a turbine wheel, disintegrates, the pieces are thrown throughout the geometric plane of rotation. If this happens while you are standing in the plane of rotation, you may be cut to pieces by flying parts traveling at speeds far above the muzzle velocity of a rifle. For this reason, always stand fore or aft of the plane of rotation when the engine is being operated on the ground. To make this danger area easy to locate, a painted RED line usually marks the danger point on the aircraft. If there isn't a red stripe, you should check the applicable technical order to determine exactly where the plane of rotation of the engine turbine is located.

The cartridge starter. Many jet aircraft use an explosive charge to start the engine. This cartridge starter is essentially a small turbine which is rotated by a blast from a high-powered cartridge. The explosive charge used in

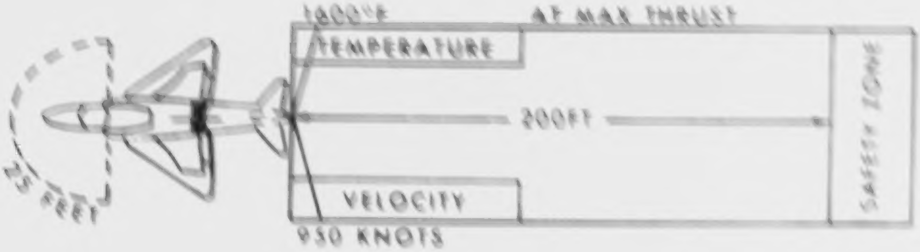


Figure 3-10. Intake and exhaust danger areas.

these cartridges produces very toxic fumes, so always stand upwind and out of the turbine wheel plane of rotation when cartridges are being used to start the engines.

Auxiliary air inlet doors. These doors may be found on the engine cowling or any other part of the aircraft. They may be used to provide air to many different types of equipment. You must not place your hands or fingers on or in auxiliary air inlet doors because they operate automatically and may open or close. If open, access doors must be secured or removed before working in that area.

Heat. Your job frequently requires you to work on engines which are operating or have recently been operating. The engine casing and exhaust case and nozzle reach extremely high temperatures. If the nature of your work will not permit you to wear gloves or other protective equipment, then you must wait until the engine cools.

Noise. The noise level is also a significant danger, in that it will ultimately reduce a person's hearing ability. If not respected, the noise could cause serious damage to your hearing, maybe even deafness. Extremely loud noise can interfere with speech communications and cause mental and physical fatigue, which in turn could jeopardize your concentration and job performance.

The Air Force recognizes the seriousness of the hazard and issues ear muffs and ear plugs which comply with the OSHA standard. One of these protective devices must be used when in high intensity noise areas. These devices offer the protection needed while performing your job. To insure that the protective devices you are using are adequate, your supervisor should enroll you in the Hearing Conservation Program, in accordance with AFR 161-35, Hazardous Noise Exposure. Under this program, your hearing is tested at least annually at many different intensities, frequencies, and durations to determine if you have suffered any hearing loss. If your hearing has been damaged, corrective measures will be implemented to prevent any further damage. Once damaged, your hearing ability cannot be restored to what it was before the damage occurred; therefore, it would behoove you to use the necessary protective equipment.

Propellers. Danger areas for propeller-type aircraft are similar to those of jet aircraft and also require that you be alert and careful. There have been cases when persons, preoccupied with something, have walked right into a turning propeller and "right out of this world." Your best insurance against this danger is to keep alert and keep aware of the danger areas. The plane of rotation of a turning propeller is also a danger area. If the engine is a turboprop type, additional danger areas include the plane of rotation of the exhaust turbine wheel, jet intake ducts, and jet exhaust blast.

How many times have you heard the story of the supervisor sending a 3-skill-level specialist out to get a gallon of "prop wash"? The young specialist is sent from one section to another until he eventually comes to the conclusion that there is no such thing. This is, of course, not true. There is such a thing as prop wash, and it can be dangerous. In fact, propeller wash can be compared to a giant fan. It has often thrown dirt and other particles into people's eyes, turned over equipment, or blown away books, papers, or other debris, which all add to the foreign object damage on the flight line.

Exercises (069):

1. List seven danger areas of operating jet engines about which instrument personnel should be concerned.

2. What is normally the minimum safe distance to the side of a jet engine intake?

3. Why is jet engine exhaust hazardous?

4. Where should you stand or work in relation to the turbine wheel plane of rotation when the engine is running?

5. How can you usually identify a turbine wheel plane of rotation?

6. Give two hazards associated with cartridge starters.

7. Why are auxiliary air inlet doors dangerous?

8. List three possible results of excessive noise exposure.

9. What can be done about a hearing loss?

070. List the various maintenance stands, and specify their constructional features, uses, and associated hazards.

Maintenance Stands. These stands are designed to provide working platforms at variable heights. A basic stand consists of a base assembly, upper structure assembly, platform assembly, and on the larger stands, a hydraulic system for raising and lowering the platform.

You should be familiar with maintenance stands in order to select and safely use the proper one for each job. There are several types of stands (work platforms) in common use. We shall discuss the most common stands that you will most likely encounter.

Type B-1 maintenance stand. This stand is a hydraulically operated combination of stair structure and work platform, mechanically linked together to enable each to remain level throughout the height range of the stand (see fig. 3-11). The platform height is easily adjusted by a hydraulic hand pump to any height between its adjustment limits of from 3 to 10 feet. Stair support members and stair handrails are rigged in a manner to make them self-aligning at all platform levels. The handrail feature of both the stairs and the work platform permits personnel to work at various extended heights in relative safety.

The base of the stand, made of welded tubular steel, is 11 feet long and 4 feet wide. A cylindrical hydraulic fluid reservoir is welded across the width of the frame. The platform-lifting mechanism is a hydraulic cylinder assembly. It is actuated by a hydraulic hand pump also mounted on the base. The hydraulic cylinder assembly connects the base to the upper structure to give lift. It also gives support to the upper structure to give lift, and it gives support to the stairs and platform in all raised positions of the platform.

The B-1 maintenance stand has a tow bar bolted to the front of the base frame and a wheel mounted at each corner of the base. The two rear wheels are equipped with 16-inch pneumatic tires and do not swivel. The front wheels are casters with ball bearings on the wheel axles and the pivot shafts. This stand was designed to be towed by a vehicle with the front wheels off the ground. The caster front wheels make turning the stand possible.

Two base locks are bolted to the forward end of the frame to prevent movement of the stand during use. They give stability to the stand when the platform is extended. The locks are spring-loaded, vertical-steel stems equipped with foot plates. When the foot pedal is pressed downward, the plates sit on the floor. In the down position, the locks tend to relieve the weight resting on the casters and prevent their movement.

The hydraulic cylinder holds the platform at the desired height. To prevent accidental lowering of the cylinder, a safety lock is used. The lock is a U-shaped steel device designed to fit into grooves cut into the cylinder assembly. It is attached to the stand by a length of chain to prevent its being lost or otherwise separated from the stand. You are required to install this lock before you climb the stairs to the platform.

The hydraulic system supplies fluid under pressure to the cylinder assembly. Hydraulic fluid from the hand

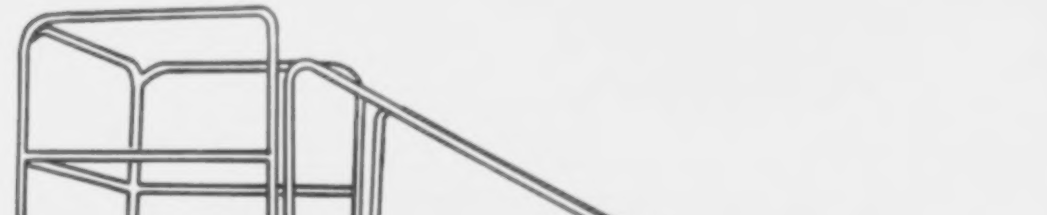


Figure 3-11. B-1 maintenance stand.

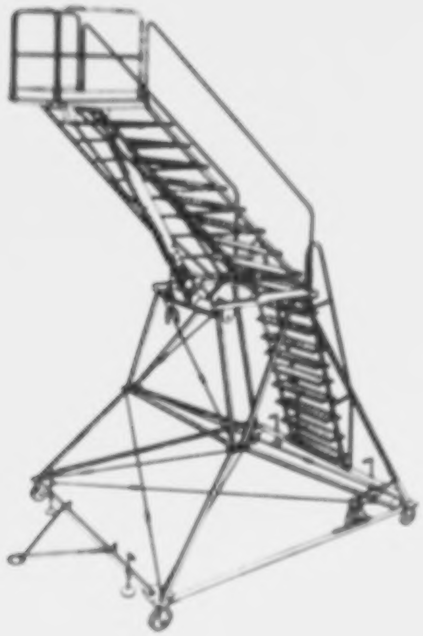


Figure 3-12. B-2 maintenance stand.

pump goes through a hose to the lower end of the cylinder. Pumping the hand pump causes the cylinder assembly to extend. A bypass valve, when in the closed position, traps pressure in the cylinder. When the bypass valve is opened, the pressure is released and the fluid returns to the reservoir, bypassing the hand pump. This allows the cylinder to retract and lower the work platform. The amount of bypass valve opening controls the speed at which the platform is lowered.

The stair support assembly consists of two oblong box sections made of welded steel tubing. These two sections are attached by pivot pins to the base assembly at the bottom. The platform is also attached to these sections by pivot pins. The stairs are mounted between these two sections. They remain parallel to the base at all platform levels. The stair handrail and posts are hinged at both the stair support frames at all times.

The work platform is mounted on the upper structure of the stair support assembly. It is approximately 4 feet square. It is made of 1-inch plywood and covered with dimpled sheet metal panels. The platform is bolted to the upper structure and supported by steel channels. This enables it to sustain a static load of 1,500 pounds. However, the platform should never be raised when it is carrying a load greater than 500 pounds.

Type B-2 maintenance stand. The type B-2 maintenance stand, as shown in figure 3-12, has a stand permanently mounted on a base extension structure of fixed height. This extension base, fabricated of angle iron and steel tubing, is 10 feet in height. This arrangement results in a maintenance stand which has a base structure of fixed height, and an upper stair structure and work platform which is hydraulically varied in height. Thus, the B-2 stand is suited for performing maintenance work and inspection of such components as aircraft vertical stabilizers and rudders that often extend to great heights above the ground level.

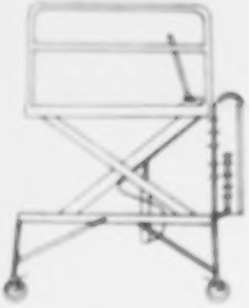


Figure 3-13. B-4 maintenance stand.

The base of the B-2 lower stand is constructed of four angle irons connected to form a rectangle which measures approximately 10 x 14 feet. To make the entire stand portable, four pivot-type casters with individual locking devices are mounted at the corners of the base. Upright structural members of steel tubing are bolted to the rectangular base at each corner. On the top of the upright structural members is attached a small base upon which is mounted the standard stair and platform assembly of the type B-1 stand. A ladder equipped with steel steps and handrails is provided to gain access to the upper portion of the stand. In addition to the structural members described, the base structure also employs steel tie rods to provide added rigidity to the stand. The stand is also equipped with four adjustable screw-type pads which may be used to level and immobilize the unit.

The hydraulic system units, including the hydraulic cylinder lift assembly, are identical to those used on the B-1 stand. The hydraulic system installation varies only in that the location of some hydraulic units are changed. However, despite these changes, the operation of the hydraulic system remains unchanged.

Type B-4 maintenance stand. This platform (fig. 3-13) is a scissors-type variable-height platform. It is mounted on a caster-equipped base. Each wheel has a brake and also can be locked at each 90° position. A hydraulic actuator near the bottom of the platform is used to vary the height of the platform from 3 to 7 feet. A reservoir

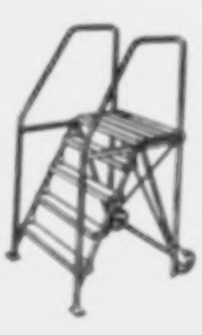


Figure 3-14. C-1 maintenance stand.

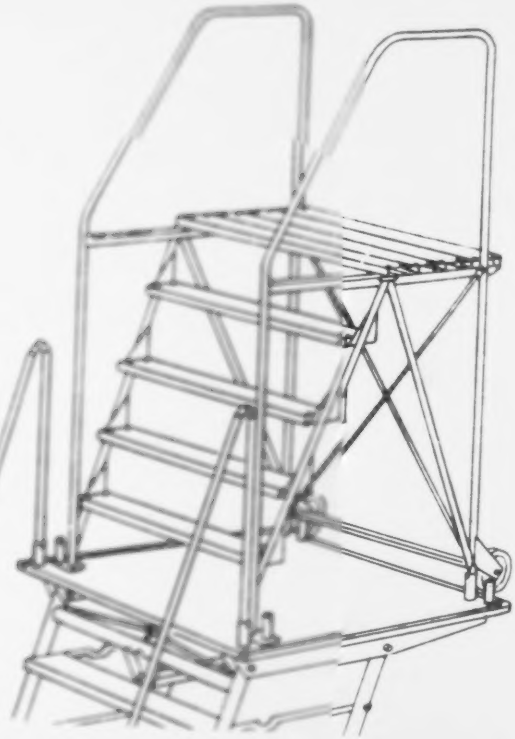


Figure 3-15. C-1 stand mounted on a B-1 stand.

with a hand pump and control valve is mounted on the platform near the ladder.

Type B-5 maintenance stand. This platform is a scissors-type variable-height platform, just like the B-4 stand, mounted on a long-legged caster-equipped base. A hydraulic actuating cylinder near the bottom of the platform is used to vary the height of the platform from 7 to 12 feet. A hand pump is used to supply pressure to the actuating cylinder. The hand pump and control valve are mounted on top of the system reservoir. The reservoir is mounted on the platform near the top of the ladder. The B-4 and B-5 stands are equipped with locking pins which fit in holes along the sides of the work platform.

CAUTION: The B-4 and B-5 platforms should never be raised or lowered while standing on the ladder. Serious injury to your feet may occur.

Type C-1 maintenance stand. This stand is also called the crew chief stand. As you can see (fig. 3-14), it is a nonadjustable 4-foot-high platform. It has wheels on the back legs so it can be easily moved from one area to another by one man. When the C-1 stand is set in position, the wheels leave the ground and the stand sits on its four legs. The C-1 stand can be used independently, or it can be installed as an extension on the B-1 and B-2 maintenance stands (see fig. 3-15).

Remember AFOSH Standard 127-9? This standard applies to all of the stands you have studied. It gives the rules and requirements for their design, construction, and use. All raised platforms present a potential for severe injury from falls or falling objects. Unsafe acts, such as standing on or removal of guardrails and toeboards, nonuse of locking devices, and failure to secure tools and equipment are just some of the causes of mishaps. These hazards can be reduced by training our people and by supervisors enforcing safe work practices.

Again we must stress, your own personal SAFETY is primarily YOUR RESPONSIBILITY.

Exercises (070):

1. What do the principal parts of a maintenance stand consist of?

2. List five commonly used maintenance stands.

3. How do you lock the hydraulic cylinder used to raise the B-1 and B-2 platforms?

4. Which of the maintenance stands is nonadjustable?

5. What are maintenance stands designed to do?

6. What precaution should be taken when you raise or lower a scissors-type maintenance stand?

CHAPTER 4

Career Field Reference Material

ALL AIR FORCE activity is, in some way, governed by written publications. As an avionics instrument specialist or technician, you need to use many different types of Air Force publications. AFOSH standards, regulations, manuals, and technical orders are just a few. You will use these publications more and more as your skills and responsibilities increase.

4-1. Air Force Publications

The publications which you will be concerned with are those that have a direct bearing on your career and those pertaining to the avionics instrument career field. You have already been exposed to AFR 39-1, *Airman Classification Regulation*, which was used in assigning you to your career field. Also, you should already be familiar with AFR 35-10, *Dress and Personal Appearance of Air Force Personnel*, which prescribes the standards we should all strive for to maintain in the wear and appearance of our uniforms. There are many other regulations and many types of Air Force publications. You need to learn about these publications, how to locate them, and how to use them.

071. Describe the general classes and subclasses of Air Force publications.

Classes of Publications. Air Force publications contain essential guidance and information to accomplish the Air Force mission at all levels of command. They may be divided into the two general classes: departmental and field. Departmental publications are issued by (or for) Headquarters USAF. They apply to at least two or more major commands, such as the Military Airlift Command or Strategic Air Command—never to only one comma[illegible] AFR 66-1, *Maintenance Management*, AFR 35-10, and AFR 39-1 are good examples of departmental publications.

Field publications are issued to major command level or below and apply to all units or activities within the issuing organization, for example, Air Training Command Regulation (ATCR) 51-27, *Instructor Qualification and Training*.

These two general classes are further divided into (1) standard publications and (2) specialized, miscellaneous, and other publications.

Standard Publications. Standard publications are used to announce policies, assign responsibilities, prescribe procedures, direct actions, and inform or motivate personnel. Let's examine these standard publications and their specific uses.

Air Force regulations (AFRs). Regulations contain directive and policy material and assign responsibilities. They may include procedure details when necessary. Regulations are usually permanent, but when it is known that a regulation will cease on a specific date, the expiration date is included. Air Force regulations are the most numerous of all Air Force standard publications.

Air Force manuals (AFMs). Though manuals usually give detailed instructions (procedures and techniques) that tell personnel how to perform their duties, they also may be general and deal with principles or doctrine. A manual may direct the step-by-step performance of a specific task, or it may include policies and assign responsibilities if these are not covered in AFRs and other pertinent publications. Because they have no unique characteristics which distinguish them from regulations, manuals are redesignated as regulations as they are revised, with the exception of AFM 67-1, doctrine and training manuals, and how-to-do-it manuals.

Air Force pamphlets (AFPs). Pamphlets usually contain information of a nondirective nature. They are written in an informal style and are usually published in brochure or booklet form. They are permanent but may contain an expiration clause. AFP 50-34 is an example previously mentioned which you should learn very thoroughly.

Operating instructions (OIs). Operating instructions are similar to regulations but apply only within the issuing headquarters. These instructions are designated headquarters operating instructions (HOIs), branch operating instructions (BOIs), etc. Operating instructions must comply with higher level directives and be updated accordingly.

Visual aids. Visual aids are charts, posters, or graphic illustrations for indefinite use or display. They are used in connection with planned operations or programs. They do not include posters for temporary display.

Bulletins. Bulletins contain announcements, notices, and temporary instructions. For example, daily or weekly base bulletins fall into this category.

Staff digests. Staff digests contain summaries of significant staff actions, important announcements, and special notices. They are issued periodically, or when needed, and at various command levels.

Supplements. Supplements are used by lower headquarters to implement, amplify, interpret, or clarify a higher level publication. A supplement must not alter or change the intent of the basic publication. A lower headquarters supplement does not supplement the supplement of a higher headquarters. Supplements are filed behind the basic publication or behind the supplement of the next higher headquarters.

Specialized Publications. These publications, issued by a command, provide information of a highly specialized nature that cannot be published in a standard publication. Specialized publication systems, such as the technical order system and Career Development Course (CDC) system, are "stand-alone" systems. They do not interface with, nor can they change or supercede, any standard publication or any form or report that it prescribes. A specialized publication can only refer to a standard publication.

Periodicals. These are informally written publications, such as the *Airman* magazine, whose main purpose is to foster greater understanding and knowledge of the Air Force and its varied missions, functions, and policies. They are used by many different organizations to publish information on nondirective material. For example, *Lifeline* is a safety and occupational health journal, published by the Navy; *Driver* is a traffic safety magazine for the military driver, published by the Air Force, in cooperation with the Army and Navy; and *The MAC Flyer*, is published by and for the Military Airlift Command.

Miscellaneous Publications. These publications also have a special purpose. They include administrative orders, Air Force newspapers, base guides and directories, recruiting advertising material, and telephone directories.

Exercises (071):

1. How do standard publications differ from specialized publications?

2. What Air Force publications are written in an informal style?

3. What publications apply only within the issuing headquarters?

4. Which Air Force publications are used by lower headquarters to implement, amplify, interpret, or clarify a higher level publication?

5. Where are supplements filed in regard to the basic publication?

072. Identify and locate basic subjects, titles, and numbers used in the Air Force publication system.

Identification of Standard Publications. Because of the large number of Air Force publications, a method of quickly identifying them is necessary, and the Air Force has developed a subject and numbering system for this purpose. Basic subjects and basic numbers are assigned to publications from the list in AFR 5-1, *Air Force Publications Management Program.*

Basic numbering system. Regulations, manuals, and pamphlets have a double numbering system to simplify their reference and control. For example, consider AFR 127-101. The first number (127) is the basic number. It shows that the basic subject of the directive is safety. The second number, preceded by a dash (-101), indicates exactly what area of safety is covered. In this case, the specific title corresponding to the second number, 101, is *Accident Prevention Handbook.*

The basic number is the same for related subjects throughout the different types of publications. For example, AFR 34-32, AFR 34-6, and AFP 34-1-9 are all in the personnel services area; each has the same basic number of 34. The second number of the AFR, AFM, and AFP tells what part of the personnel services each area covers.

Note in the above example that the pamphlet has an additional or third number. The first number is the basic number; the second number provides for grouping under secondary subjects; the third number is for a more detailed breakdown. NOTE: Three-part numbers are gradually being eliminated from the Air Force Publications Library.

Supplements. Supplements are identified with the basic publications that they supplement and are numbered in sequence; for example, ATC Supplement 1 to AFR 4-1, 18 January 1973. Remember that every Air Force publication is given a number and title. This makes it possible to index and file all publications in order. It also makes it simple for you to locate any publication quickly and easily.

Indexes for standard publications. Suppose you want to read about the Battle of Gettysburg and select a book on American History to find the information you need. Would you thumb idly through the book until you happened to find what you wanted? No, you would look in the index and turn directly to the indicated pages. Air Force standard publications, for the same reason, are indexed both numerically and alphabetically. All Air Force publication indexes use the basic number zero (0) as the first digit.

AFR 0-2, *Subjective and Numerical Index of Standard Publications and Recurring Periodicals*, lists Air Force regulations, manuals, pamphlets, and visual aids in numerical order by basic series number. The Numerical Index is divided into four basic sections: Recurring Periodicals (such as *HQ Briefs, Airman*, etc.); Visual Aids; Regulations, Manuals, and Pamphlets; and Obsolete Publications, (rescinded or superseded recently).

For each publication listed, the following information is given: number, date, title, office of primary responsibility (OPR) symbol, and distribution symbol. The latter two, OPR and distribution, are primarily of interest to those who maintain the file. A typical entry looks like this:

Number	*Date*	*Title*	*OPR*	*Distr.*
R 39-11	1 Mar 73	Airman Assignments	DPMRA	F

Since Air Force publications change frequently, the Numerical Index is revised and reprinted periodically.

Exercises (072):

1. In what regulation should you look for a list of basic Air Force subjects?

2. Air Force publications carry a double number. What do these numbers indicate and how are they used?

3. Which of the following three groups of numbers indicates an index: 34-3, 3-4, or 0-2?

4. The supervisor informs you that the manual you are reading has been rescinded by the index just received. In which section of the index has the supervisor located this information?

073. Tell how to use the publications file.

Publication Filing Methods. As a publication user, you are not charged with maintaining the files, but you are responsible for checking the currency of the publications you use. The procedure is similar for standard and for other than standard publications. Go to the official file and check the publication date in AFR 0-2.

There are several other things you should know about using AFR 0-2. This index lists regulations, manuals, and pamphlets mixed together in one section. A letter symbol identifies the type of publication. The letter R (regulation), M (manual), or P (pamphlet) precedes the publication number. The file clerk writes a status symbol in the left margin in front of each publication that has been ordered for the file. A plus (+) means that a current copy of the publication is on hand. A dash (-) means that the publication has been ordered but is not on hand. No marks are used for publications not authorized for the file. If you receive a publication change that is not printed in AFR 0-2 or that supersedes the one in the current index, the clerk should write in the change.

You may borrow a publication from the official files for a maximum loan period of 3 days. Don't be too eager to get a copy for your personal use. Before long the publication may be obsolete.

Exercises (073):

1. To determine that the manual you are using is current, you check AFR 0-2 and find its date listed as 13 Sep 72. Your manual has a date of 3 May 75 on the cover sheet. To correct the index error, what should you do?

2. Looking in the index for AFR 39-62, you notice that someone has placed a dash (-) in front of the number. What does this tell you at a glance?

3. You check out an AFR from the official file on 3 May. By what date should you return it?

074. Locate master libraries and specific publications, and tell what it means to be the OPR for a regulation.

Publication Libraries (Files). To be certain that up-to-date information is always available, the Air Force prescribes the establishment of publication libraries or files with an individual assigned to keep each library or file current. There are two major types of files.

Types of publications files. One type of file is called the Master Publication Library. Such a library is authorized for any organization down to wing or base level—usually no lower. The other type of file is called the Functional Publication Library. These libraries are authorized for the lower level activities that need them. They are limited to the publications that pertain specifically to the mission of the activity.

OPR for currency of publications. Every procedure and policy is subject to change. Changes are necessary whenever new or better equipment or better ways to use it are developed. As changes in procedures or policies are introduced, the publications covering them are revised, changed, or rescinded. The responsibility for keeping publications current first belongs to the office of primary responsibility (OPR). From there it goes to each individual charged with maintaining the library or file. AFR 5-31, *Publication Libraries and Individual Publications Sets,* prescribes general policies for maintaining files and indexes.

Exercises (074):

1. Designate the lowest command level in which master libraries are normally located.

2. Publications that are used almost daily are normally found in what library?

3. What does a supervisor mean when he or she says that a certain shop is the OPR for a regulation being printed?

4-2. Technical Orders

Technical orders (TOs) are specialized publications in that they are the source of information for the specific equipment with which you are working. In technical orders you find specific instructions, as well as general information about such tasks as operating, servicing, inspecting, maintaining, modifying, and overhauling Air Force equipment. Each time equipment is repaired, a technical order must be used for reference. We will use two procedural TOs for our source of information: (1) TO 00-5-1, *Technical Order System*, which describes the system; and (2) TO 00-5-2, *Distribution and Storage of AF Technical Order System Publications*, which outlines the procedures for obtaining TOs. We will now discuss the TO numbering system.

A specific numbering system is used to identify all publications belonging to a technical order group. The number is made up of three or more parts, each part being separated by a dash.

075. Specify the meaning of selected portions of aircraft technical order numbers.

Air Force Technical Order Numbering System. Each TO has a number similar in purpose to your social security number. This number distinguishes one TO from another. It is usually a combination of numbers and letters. It provides a systematic grouping of technical publications. Each TO number is usually divided into three, four, or five parts. We will analyze TO numbering, focusing on the three-part and four-part number.

Three-part number. TO numbers are separated (by dashes) into parts. An example of a three-part number is 1C-141A-4.

Each part of the TO number has a definite meaning. The first part is a number designator that identifies the TO category, plus a letter designator identifying the type of aircraft. The 1 identifies aircraft in general; a letter is normally used to identify the type. Here are a few examples:

1A Attack Aircraft
1B Bomber Aircraft
1C Cargo Aircraft
1F Fighter Aircraft
1H Helicopter Aircraft
1L Observation Aircraft
1T Trainer Aircraft
1U Utility Aircraft

The second part identifies aircraft model, series, and configuration. Design changes to permit a different use of an aircraft are usually shown by letters in parentheses in the TO number. Here are a few examples, read in sequence from left to right.

1C-141A- = Aircraft, Cargo; Model 141; Series A
1B-52H- = Aircraft, Bomber; Model 52; Series H
1C-135(K)A- = Aircraft, Cargo; Model 135; Modified to be a tanker, Series A

The third part of the number identifies the kind of TO. In Category 1 (aircraft TOs) those which cover similar subjects are assigned similar numbers. Here are some examples of third-part numbers and subjects which are the same for most aircraft.

1B-52G-1	Flight Manual
-2	Maintenance Instructions
-3	Structural Repair Instructions
-4	Illustrated Parts Breakdown
-5	Basic Weight Checklist
-6	Scheduled Inspection and Maintenance Requirements

Three-part numbers also include a lot of general TOs. They can be identified by the zero, double zero, or the lack of a letter in the first part of the number. For example:

00-5-1	AF Technical Order System
00-20-2	The Maintenance Data Collection System
1-1-300	Acceptance/Functional Check Flight and Maintenance Operational Checks
1-1-688	Use of Electrical Equipment in Hazardous Areas

Four-part number. As in the three-part number, the

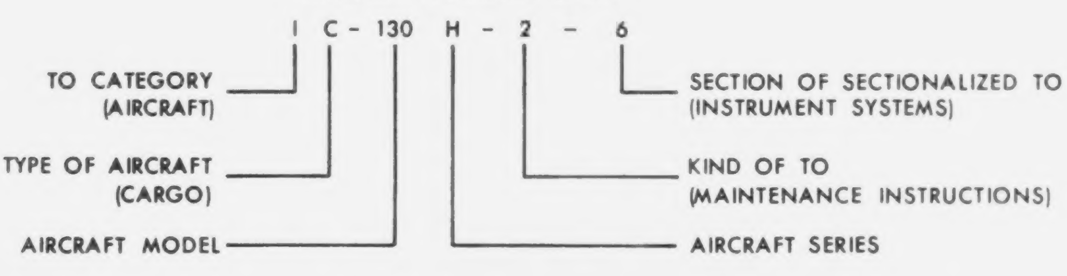


Figure 4-1. Aircraft technical order number.

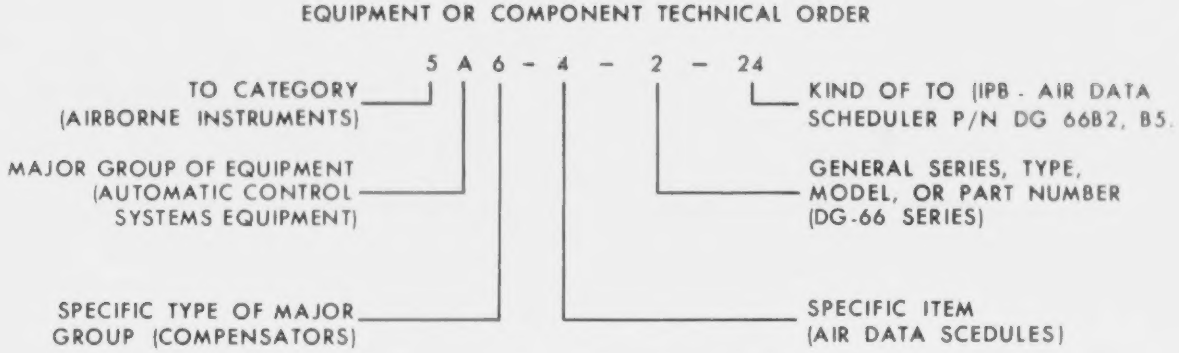

EQUIPMENT OR COMPONENT TECHNICAL ORDER
5 A 6 - 4 - 2 - 24
TO CATEGORY (AIRBORNE INSTRUMENTS)
MAJOR GROUP OF EQUIPMENT (AUTOMATIC CONTROL SYSTEMS EQUIPMENT)
SPECIFIC TYPE OF MAJOR GROUP (COMPENSATORS)
KIND OF TO (IPB - AIR DATA SCHEDULER P/N DG 66B2, B5.
GENERAL SERIES, TYPE, MODEL, OR PART NUMBER (DG-66 SERIES)
SPECIFIC ITEM (AIR DATA SCEDULES)

Figure 4-2. Equipment or component TO number.

first part of the four-part number (fig. 4-1) consists of a number designator which identifies the TO category, plus a letter designator which identifies the type of aircraft. The second part identifies aircraft model series; the third part identifies the kind of TO and an individual TO; while the fourth part identifies a section of a sectionalized TO. For example:

1C = Aircraft, cargo
1C-130H- = Aircraft, cargo; Model 130; Series H
1C-130H-2- = Aircraft, cargo; Model 130; Series H; Maintenance instructions
1C-130H-2-6 = Aircraft, cargo; Model 130; Series H; Maintenance instructions; Instruments

Equipment TOs (fig. 4-2), other than aircraft, also fall in the four-part number and longer categories. The first part of the number normally consists of three designators. The first designator is numerical and identifies the TO category. For example:

5 Aircraft and Missile Instruments

The second designator is alphabetical and identifies a major group of equipment; e.g.:

5E Engine and Temperature Instruments

The third designator is numerical and identifies a specific type of major group; e.g.:

5E5-	Generators
5E6-	Indicators

The second part of a four-part TO number identifies a general technical order series or an equipment type, model, or part number; e.g.:

5E5-3-	Generators, electric tachometer
5E6-3-	Engine Indicators, temperature

The third part of the four-part TO number identifies a general series, an equipment type, model, or part number; e.g.:

5E5-3-20-	Generators, electric tachometer; Type GEU-7/A, miniature
5E6-3-25-	Indicators, temperature; P/N152B series

The last part of the four-part TO number identifies the kind of TO; e.g:

5E5-3-20-22	Generators, electric tachometer, Type GEU-7/A miniature; Checkout and service sheet
5E6-3-25-3	Indicators, temperature; P/N152B series; Overhaul instructions with parts breakdown

Five-part, six-part, and succeeding parts. These are used in some categories. They are used to further break down an equipment group that is too complex for the four-part number to handle. The index for the specific category explains the parts for these TO numbers.

An important fact to know about six-part and longer TO numbers is that they will probably have letters within the TO number which identify the type of TO. For example:

1B-52G-2-11JG-1

The -11 identifies instruments, the JG says it's a job guide, and the -1 identifies it as the first of a series of job guides on instruments.

Other letters you may come across include the following:

CL	Checklist
FI	Fault Isolation
GA	General Airplane
GS	General System
MS	Maintenance Support
S	Operational Supplement
SC	Sequence Chart
SS	Safety Supplement
TS	Troubleshooting
WC	Workcard
WD	Wiring Data
WS	Worksheet

Some examples are:

1B-52G-2-11MS-4	Maintenance Support Instruments
1C-130H-2-8CL-1	Organizational Maintenance Checklist, C-12 Compass
1C-135(K)A-2-13GA-1	General Airplane, Hydraulic Pressure Supply System
1C-141A-2-6TS-1	Troubleshooting Instruments

Exercises (075):

1. What do the first, second, and third parts of a three-part aircraft TO number indicate?

2. What do the letters "MS" indicate when used within a TO number?

3. Explain the meaning of the fourth part of a four-part TO number.

4. What are the fifth and sixth parts of TO numbers used for?

5. State the type of TO for each part of a three-part number listed below.
   a. First part, 1C-.
   b. First part, 0-.
   c. First part, 00-.
   d. Third part, -4.
   e. Third part, -6.

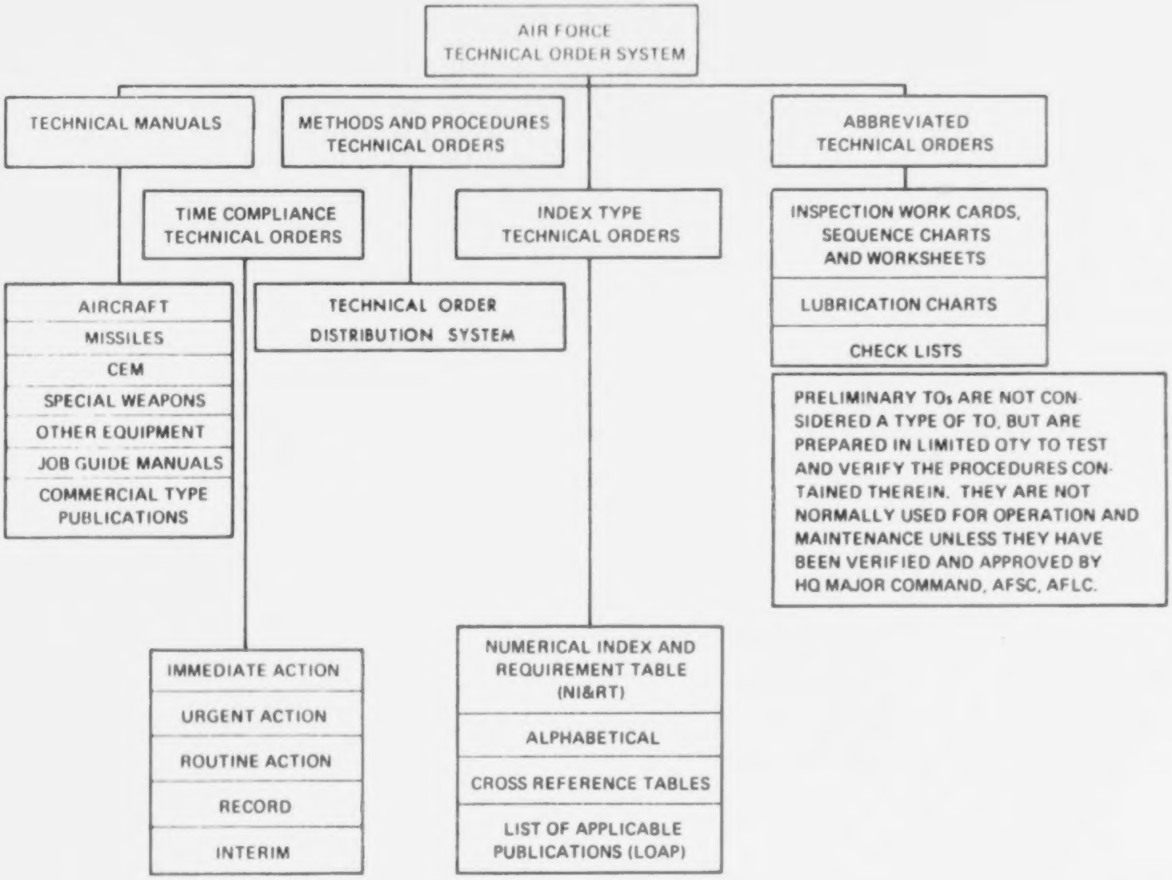

AIR FORCE TECHNICAL ORDER SYSTEM
TECHNICAL MANUALS
METHODS AND PROCEDURES TECHNICAL ORDERS
ABBREVIATED TECHNICAL ORDERS
TIME COMPLIANCE TECHNICAL ORDERS
INDEX TYPE TECHNICAL ORDERS
INSPECTION WORK CARDS, SEQUENCE CHARTS AND WORKSHEETS
LUBRICATION CHARTS
CHECK LISTS
AIRCRAFT
MISSILES
CEM
SPECIAL WEAPONS
OTHER EQUIPMENT
JOB GUIDE MANUALS
COMMERCIAL TYPE PUBLICATIONS
TECHNICAL ORDER DISTRIBUTION SYSTEM
PRELIMINARY TOs ARE NOT CONSIDERED A TYPE OF TO, BUT ARE PREPARED IN LIMITED QTY TO TEST AND VERIFY THE PROCEDURES CONTAINED THEREIN. THEY ARE NOT NORMALLY USED FOR OPERATION AND MAINTENANCE UNLESS THEY HAVE BEEN VERIFIED AND APPROVED BY HQ MAJOR COMMAND, AFSC, AFLC.
IMMEDIATE ACTION
URGENT ACTION
ROUTINE ACTION
RECORD
INTERIM
NUMERICAL INDEX AND REQUIREMENT TABLE (NI&RT)
ALPHABETICAL
CROSS REFERENCE TABLES
LIST OF APPLICABLE PUBLICATIONS (LOAP)

Figure 4-3. Block diagram (chart) of types of TO publications.

076. Identify the types of technical manuals which may be found in a maintenance shop.

Technical Manuals (TMs). The types of TOs authorized for issue and use are technical manuals, methods and procedures technical orders, index type technical orders, time compliance technical orders and abbreviated technical orders, as shown in Figure 4-3. These TOs are published for Air Force systems and equipment including aircraft, missiles, engines, test equipment, parts, etc. They cover organizational, intermediate, and depot levels of maintenance. These manuals cover the installation, operation, maintenance, and handling of Air Force equipment and material. In figure 4-3 you can see that technical manuals are divided into seven different types. We will discuss only those which you must use.

Aircraft Technical Manuals (TOs). There are various types of aircraft technical manuals. Each type is identified by a numerical designator. This designator is the third part of the TO number. Common designators are -1, -2, -4, and -6.

Flight manuals. The -1 identifies flight manuals; for example, TO 1B-52B-1, Flight Manual for the B-52B, C, and D Aircraft. A flight manual, including this one, describes a specific aircraft, its equipment, operation, characteristics, emergency procedures, and operating limitations. It contains enough information to insure that each mission can be completed safely. You need to use flight manuals frequently to determine which colors of range markings to use on indicators and where they should be placed.

Maintenance manuals. When the -2 is the third part of the TO number, it identifies a TO containing organization (flight line) maintenance procedures, including troubleshooting, adjusting, cleaning, draining, lubricating, removing and replacing units and components, and testing. Two examples of organizational maintenance manuals are 1C-5A-2-6, *Organizational Maintenance—Instruments—C5A*, and 1F-4D-2-11, *Maintenance Instructions—Instrument Systems—F4D*.

Illustrated parts breakdown (IPB). The dash four (-4) identifies an illustrated parts breakdown, sometimes referred to as a parts catalog. These TOs illustrate and list all parts, subassemblies, and assemblies of equipment. They are used for identifying and ordering parts. They reflect the sequence of assembling and disassembling parts and assemblies, but do not contain the necessary instructions to permit proper assembly. Two examples of IPB manuals are as follows:

1F-106A-4	Illustrated Parts Breakdown—F106A
1F-4G-4-4	Illustrated Parts Breakdown—Instruments, Electrical and Electronic Systems—F4G

The last -4 in TO number 1F-4G-4-4 indicates that this is the fourth manual in this series of IPBs on the F4G aircraft.

Aircraft inspection requirements manuals (-6). These manuals contain all the information that is needed for periodic maintenance of accessories and components of a specific aircraft. An example of an aircraft inspection requirement manual is TO 1F-4C-6, Inspection Requirements—F-4C, D and RF-4C Aircraft.

Work unit code manuals (-06 TO). These manuals contain codes used to report maintenance actions under the maintenance data collections system.

General manuals. In addition to the specific aircraft publications, there are general manuals which cover several items of equipment in several series. These general manuals can be identified by their numerical designators, which may be any number from -101 to -500; for example, 1F-4-101, Collection and Reporting of VGH Flight Recorder Data and Statistical Accelerometer Data—F4 and RF4.

Other equipment technical manuals (TOs). These manuals pertain to equipment other than aircraft, missiles, and nuclear weapons. A glance through TO 0-1-01, which is the index to all individual numerical indexes, shows that approximately 50 categories and subcategories could have technical manuals. Of these 50 general categories, you'll find that many of the technical information publications have been prepared for such items of equipment as follows:

- Aircraft engines.
- Airborne electronics.
- Test equipment.
- Field and shop equipment.
- Standard commercial equipment.
- Training devices.

Job guide manuals. Job guide manuals are reduced-size technical orders. They are essentially technical manuals which contain detailed information and instructions required for the flight line operation, maintenance, servicing, and inspection of aircraft and aircraft systems. This grouping of TOs is divided into many parts: general aircraft (GA), maintenance support (MS) or troubleshooting (TS), and job guide (JG). The general aircraft (GA) manual provides a description of the instruments or applicable system, and is intended to provide the technician the basic understanding of the system, which is a prerequisite to performing troubleshooting and related maintenance procedures. The letters "GA" are included in the TO's numerical designator; i.e., 1B-52H-2-11GA-1. The maintenance support (MS) or troubleshooting (TS) manuals provide general and detailed troubleshooting instructions which should be used to isolate a malfunction to a line-replaceable component or to defective aircraft wiring. The letters "MS" or "TS" are included in the TO's numerical designator; i.e., 1B-52H-2-11MS-1 or 1C-141A-2-9TS-3. The job guide (JG) manuals provide the specifics for any given task accomplishment. The specifics include all supplies and parts required, number of personnel required, special tools and test equipment required, additional data required, and the desired equipment condition, such as power on or off and fuel tanks full or empty. Because of the varied assignment of responsibility between Air Force organizations, no attempt has been made to designate the type of specialist required to perform a specific task or function.

Regardless of the technician's specialty, the procedures contained in the applicable equipment manual should be followed when performing maintenance. The letters "JG" are included in the TO's numerical designator; for example, 1B-52G-2-11JG-8. The information included in each GA, JG, MS, or TS manual is listed in that manual by the table of contents.

Commercial publications. Commercial publications that come under the category of technical manuals are normally furnished by the manufacturer of equipment bought by the Air Force. It is frequently packed in the same box with new equipment. It may furnish instructions on the assembly, installation, operation, servicing, overhaul, and parts identification of the manufacturer's product. Sometimes commercial publications are identified by the Air Force as TOs. These publications are to be used until formal printed TOs become available. For example,1C-12A-4 identifies a commercial manual titled "Parts Catalog—No 92-37445-2—(Beechcraft Model A200—C12A)."

Commercial publications may be ordered through publication requirement tables when technical order numbers have been assigned to them. Publications on the types of equipment which are not covered in technical orders may be purchased in your local community. Commercial manuals, bought by the Air Force or furnished with Air Force equipment, are not the personal property of any individual. They are to be maintained in the authorized TO file for the shop to insure that they are available to all personnel who need them.

Exercises (076):

1. List five types of technical orders (TOs) which are authorized for Air Force use.

2. What are technical manuals?

3. Which TO would you use to find the aircraft engine operating limitations?

4. What would be the third part of TO 1F-5B- if the TO contained instrument systems maintenance instructions?

5. Give the kind of TO for each of the following.
   a. 1B-52H-1.
   b. 1C-130E-2-.
   c. 1C-141B-4.
   d. 1F-4C-6.
   e. 1T-43-101.
   f. 1C-135(K)A-2-11MS-3.

077. Describe methods and procedures TOs, and state how they aid in operating an instrument shop.

Methods and Procedures Technical Orders. Publications of this type provide information and instructions in various subject areas for supervisory and administrative personnel. These TOs include the following publications.

00-5 series, Air Force Technical Order System
00-20 series, Maintenance Management System
00-25 series, Miscellaneous TOs
00-35 series, Administrative TOs
00-75 series, Air Evacuation
00-100 series, Quality Control

Methods and procedures type TOs are printed in the same format as are aircraft and equipment technical manuals. A complete listing of these publications is found in TO 0-1-02, which is the index to general publications in the 00 category.

Exercises (077):

1. In what way do methods and procedures TOs aid in the operation of an instrument shop?

2. What TO category do methods and procedures TOs come under?

078. Differentiate between TCTOs and give examples of each.

Time Compliance Technical Order. Time compliance technical orders (TCTOs) are the media through which modification and modernization programs are directed. TCTOs can be identified by their numerical designators, which will be -501 and higher. Some examples are:

1F-5F-501	Standby Attitude Indicator Replace ARU-32/A with ARU-42/A-1
1B-52-2187	Installation of ARU-30 Attitude Indicator B-52D, B-52G, B-52H

TCTOs are grouped according to their urgency. Notes preceding the text state the degree of the urgency, when the work will be done, and by whom it will be performed.

Immediate action TCTOs. This type of TCTO is issued to correct existing unsafe conditions that could result in fatal or serious injury to personnel. The TCTOs are also issued to prevent possible damage to, or destruction of, valuable property. These TCTOs require a specific action immediately or the aircraft cannot be flown or the equipment cannot be used.

On the top of the first page, the words "IMMEDIATE ACTION" are printed in red. To further focus attention on immediate action TCTOs, red Xs are printed around the entire border of the page. The red Xs provide distinct identification and correspond to the symbol used on maintenance forms.

Urgent action TCTOs. This type of TCTO is used to correct potentially hazardous conditions or conditions affecting mission necessity. These are factors that could result in injury to personnel, damage to valuable property, or unacceptable reduction in operational or combat efficiency.

The words "URGENT ACTION" are printed in red at the top of the first page. A series of circled red Xs, alternately spaced with red diagonals (/) are printed around the border of the page. Upon receipt of the TCTO, the aircraft or equipment is placed on a red diagonal, indicating that an unsatisfactory condition exists but is not sufficiently urgent or dangerous enough to cause the aircraft to be grounded or the equipment not to be used. If the required action has not been accomplished by the end of the time specified in the TCTO, which may be from 1 to 10 days from receipt, the symbol on the maintenance forms must be upgraded to a circled red X.

Routine action TCTOs. This type TCTO is used for correction of equipment or procedural deficiencies that could constitute a hazard through prolonged usage. These TOs are without distinguishing red symbols. They are issued in two separate categories (category 1 or 2), based on the primary responsibility for accomplishment. Category 1 TCTOs require compliance by organizational and field maintenance activities. Such orders specify that work must be done within 30 to 180 days (the number of days indicating the degree of the urgency) or not later than one of the next two scheduled periodic inspections. Category 2 TCTOs require compliance by depot-level maintenance activities. These orders require that the necessary work be done during the next IRAN (inspection and repair as necessary) or overhaul.

Exercises (078):

1. What is the primary difference between immediate and urgent action TCTOs?

2. What are the distinguishing features of TCTOs?

079. Name the type of index used for locating specific information.

Index Type Technical Orders. These TOs show the status of all TOs. They provide a means of selecting needed TOs and group TOs pertaining to specific items of equipment. You will need to refer to indexes to find out if there is a current TO covering your particular subject matter. Technial order publications have alphabetical and numerical indexes. Also available are specialized listings of applicable publications and cross-references of equipment part numbers and type numbers to applicable TO numbers.

Alphabetical index. TO 0-2-1, *Alphabetical Equipment List Cross-Reference with Technical Order Number Groups*, gives the alphabetical listing of the number groups for TOs as those number groups are set up in the numerical indexes. When the type of equipment is known, such as actuator, generator, indicator, screwdrivers, or sextants, this index provides an easy method for locating the correct technical publication number group. The preface of the TO gives detailed instructions on its use.

Numerical index. TO 0-1-01, *Numerical Index, Alphabetical Index, and Cross-Reference Table Technical Orders*, is a single document which lists all of the categories within the TO system, as well as supplements to each category's numerical index and requirement table (NI&RT).

Actually, the -01 publication is a numerical index of all authorized individual indexes. Each NI&RT (numerical index) covers a category of TOs based on the functional usage or family grouping of equipment. The NI&RT category can be determined from the first part of the TO number.

For example:

TOs beginning with	*are covered in NI&RT*
0-	0-1-01
00-	0-1-02
1-	0-1-1-1
1B-	0-1-1-2
1C-, 1E-	0-1-1-3
1F-	0-1-1-4
1A-, 1H-, 1I-, 1T-, 1U-	0-1-1-5
5	0-1-5-1
5A, 5F	0-1-5-2
5E, 5L, 5M, 5P	0-1-5-3
5N	0-1-5-4
32	0-1-32
33-, 33A	0-1-33-1

Cross-reference indexes. TO 0-4-2, *Cross-Reference Table of Time Compliance Technical Order Numbers to Applicable Data Code Numbers*, is used to identify date code numbers assigned to time compliance technical orders (TCTOs). The data code numbers are used for controlling and reporting TCTO accomplishment.

TO 0-4-6-1, *Numerical Cross-Reference Index-Equipment Numbers to Technical Order Numbers*, provides an easy means of locating the required TO number when you know the equipment part number, type number, or military specification number.

List of Applicable Publications (LOAP). This document lists all TOs that apply to a specific aircraft type. The LOAP helps you determine the contents of a limited TO tile that you may need to establish. For example, TO 1C-10(K)A-01, *List of Applicable Publications—KC-10*, lists all TOs required to maintain the KC-10 aircraft. Note that the final designator of the LOAP is -01 and remember that it will always be -01, regardless of the type of aircraft. If you need a TO giving bench check procedures for the air data computer, you could go to the LOAP to find the number of the right TO. If you need the operating procedures for the air data computer test set or TTU-205, you can use the LOAP to find the TO number for that information too.

Exercises (079):

1. List four index-type technical orders.

2. Where would you look to determine which TO group covers tachometer generators?

3. Give two fast methods you could use to identify the TO which covers the TTU-205C/E, Pressure Temperature Tester, used on the F-15 aircraft.

4. You learned in objective number 075 that the 5 category covers aircraft and missile instruments and within that category, 5E applies to engine and temperature instruments. Which NI&RT lists engine and temperature instruments technical orders?

080. State the purpose of abbreviated technical orders.

Abbreviated Technical Orders. TOs of this type are primarily work simplification devices. Obviously, it would be difficult to carry around bulky technical manuals for instructions on various tasks, such as inspecting or lubricating equipment, components, or parts. For this reason, inspection workcards, sequence charts, and checklists have been developed in a condensed form and reduced size.

Inspection workcards. These are sets of cards which list inspection requirements, given in the -6 technical manual, in a checklist form. By being card size, these abbreviated TOs can be taken on the job while you perform a scheduled inspection. Work assignment information is given on each card. This makes it convenient when assigning work to maintenance personnel. Also, the work can be arranged by areas, leading to efficient maintenance scheduling and planning. The inspection requirements on each card are arranged to provide a logical sequence of performance. Charts on the reverse side of selected cards pictorially locate each work area and indicate the code and title of the areas referred to in each set of cards.

Inspection sequence charts. Sequence charts are used only for periodic inspections. They depict a basically planned work schedule or a sequence that permits efficient accomplishment of the concerned inspection. The charts serve as a guide in preparing the actual work schedule for each particular inspection. They are also used to control the assignment of work during an inspection.

Inspection worksheets. These constitute another form of abbreviated technical order listing the inspection requirements as a checklist. Worksheets also provide spaces to establish credit and fix responsibility for each item of the inspection. To aid you in their use, there are detailed instructions are printed at the front of each inspection worksheet.

Checklists. Originally, this type of abbreviated technical order was used only by aircraft crewmembers. The contents of such flightcrew checklists gave a series of items that could be used to perform preflight, inflight, and postflight checks.

Checklists are now available for many instrument system operational checks. These checklists contain each step that must be performed in chronological order to insure proper system operation. Like the workcard, checklists are printed in sets and in a size that is convenient to use on the job. The letters CL are part of a checklists's numerical designator.

You may encounter checklists that are authorized and prepared by the headquarters of your particular command. Other checklists may be prepared locally. In any case, the importance of following the steps given in these checklists cannot be overemphasized.

Exercise (080):

1. State the purpose of the following types of abbreviated technical orders:
   a. Inspection workcards.

   b. Inspection sequence charts.

   c. Checklists.

   d. Inspection worksheets.

081. Identify the different methods used to publish supplemental technical material.

Supplemental-Type Technical Orders. Various supplemental-type information is published for TOs. These are classified as changes, supplements, appendixes, and revisions. Each serves a specific purpose.

TO changes. Changes are issued only when parts of the existing TO are affected. On the affected pages, the obsolete material is deleted and new material is incorporated. The changed pages replace the corresponding numbered pages in the existing publications. All replaced pages are removed and discarded. Sometimes a change contains additional material that cannot be fully included on a replacement page. In this case, additional pages are issued and added to the affected publication. These additional pages bear the number of the preceding page augmented by a letter suffix. For example, additions to page 20 of a given publication are carried on pages 20A, 20B, etc., and are filed in that sequence.

Changed pages are identified by change dates printed on the bottom of each page. Changes in the text are indicated by a heavy black line in the outer margin of the page, immediately opposite the changed part of the text. A new title page is issued with each change. This new title page bears the original publication date and a change date. The word "CHANGE" is printed across the face of the new title page. A listing of the changed pages is printed on the "A" page in numerical order of their respective dates. By referring to the "A" page, you can determine the completeness and current status of the publication.

TO supplements. Supplements to basic publications are issued as separate publications. These supplements are used to incorporate, augment, or reuse data when there isn't time to include the information in a change or revision to the basic TO.

Supplements may be cumulative or noncumulative: that is, each new supplement may include all data contained in the previous supplements, or each new supplement will be used in addition to the previous supplements. They all have the same title as the basic TO. The supplement number is the same as that of the basic TO, with the addition of one or more letters or numbers. Sometimes, supplements are replaced by changes or incorporated in revisions. When this happens, the supplements are removed.

Routine, safety, operational, and identifying technical publications sheets are types of supplements you will frequently see.

a. Routine supplements are normally issued only to NI&RTs, TCTOs, and some technical manuals. TO 00-5-1A would be a routine supplement to the basic TO 00-5-1.

b. Safety supplements are a fast means of reflecting safety information in TOs when a hazardous or safety condition becomes known. These supplements contain operational, precautionary, and restrictive instructions that affect safety. TO 1B-52H-1SS-253 would be a safety supplement to the B-52H flight manual. Look at the example just given. A safety supplement can be identified by the double S in the TO number.

c. Operational supplements are issued as a fast means of reflecting information in TOs when work stoppages or mission essential operational deficiencies are involved. The 1C-10(K)A-2-31S-1 would be an operational supplement to the instrument manual on the KC-10. Notice that there is only one letter "S" attached to the basic TO number.

d. Identifying technical publications sheets (ITPS) are used to assign TO numbers to commercial or other services publications. They are identified by title only.

TO page supplements (TOPS). These are unique supplements which also differ from TO changes. A change replaces a page and a supplement is filed in front of or behind the basic TO. The TOPS page is filed in the TO facing the affected page. A TOPS may be issued only when the changed data does not warrant issuing a safety or operational supplement. TOPS are printed on green paper to distinguish them from standard changes.

Appendixes. Appendixes to publications are used to include material that is not part of the normal sequence outlined in the table of contents. Examples of such material are tables, charts, or supplementary information. Such added material becomes an integral part of the affected publications. They may be issued as a part of the basic publication or separately. In the latter case, the appendixes are issued with a changed title page to be substituted for the existing title page of the basic publication. The changed title page bears a revised publication date and a change strip. The pages of appendixes are then included at the end of the basic publication. Inclusion of an appendix in a publication is reflected on the "A" page in a manner similar to that used for change pages.

TO revisions. Revisions are complete new editions of a publication and bear a new publication date. They replace the original publication, including any existing changes, appendixes, and in most cases, all existing supplements.

Exercises (081):

1. How are changes in the text indicated?

2. When are TO supplements issued in place of regular revised pages?

3. When are TO changes issued?

4. Where is the inclusion of an appendix in a publication reflected in the TO?

5. What are revisions?

082. Give the purpose of preliminary technical orders.

Preliminary Technical Orders (PTOs). Preliminary technical orders are not considered a type of TO, but are prepared in limited quantities to test and to verify certain procedures that were developed for use with the first test or early production models of Air Force equipment. Unlike other publications in the TO system, PTOs are not controlled by the pertinent numerical index and requirement table. This type of publication is a special kind of TO. Only a few organizations are authorized to request and maintain limited files of them.

These limited TOs are identified by the word "PRELIMINARY" printed on their title page and by their sequential copy numbers; e.g., No. 5 of 200. The customary TO numbering system is used to identify PTOs, along with the usual title and A pages. Limited files of formal TOs will not include preliminary technical orders. The latter must be maintained in a separate file that must be clearly marked. Changes and supplements to PTOs are handled in the customary manner. When a PTO has been accepted and approved for Air Force operation and maintenance use, the word "PRELIMINARY" and the sequential control number are deleted from the title page. A replacement note is printed on the title page and states that the issued publication replaces the PTO (its technical order number and date).

Exercises (082):

1. What is the purpose of preliminary TOs?

2. Where are preliminary TOs maintained?

083. State the procedure for locating information in a TO.

Using a TO and the TO System. Locating information in TOs is easy once you understand the system. Using the information in the preceding paragraphs, you should have little trouble in locating a specific TO to use on the job. You learned and used much of the information during 3-level training. Now you need to practice using TOs in order to become proficient in their use.

Remember, as long as you know the subject, the name of the equipment, the part number of the equipment, or the type number of the equipment, there are indexes to help you find the right TO for it. Once you determine what the proper TO is, go to the TO file and select the one you need. You could thumb through the TO to locate the specific information desired, but you would probably be "spinning your wheels" because some TOs are quite large. The correct procedure is to go to the table of contents to determine the precise section, page, or paragraph containing the needed information. Once you find the information, follow the procedures given. They have already been tested and proven reliable by experts on the equipment.

There may be times when you will need the assistance of your OJT supervisor in the use of the TO and TO system. Don't be afraid to ask when you need help. That is why you have an OJT supervisor. Learn from his or her experiences.

Exercises (083):

1. What should you do to become proficient in the use of TOs and the TO system?

2. What is the correct procedure to locate specific information in a TO?

3. Whom should you contact when you need assistance in using a TO or the TO system?

084. Interpret specific precautionary terms (signs) used in technical orders.

Interpreting TO Information. It is true that interpretation of TOs is simply a matter of "read and heed," but it is very important that you pay particular attention to such precautionary words as "WARNING," "CAUTION," and "NOTE." These flags are intended to focus your attention on special paragraphs which will give you valuable information.

a. A "WARNING," highlighted in any manner, means that a violation of the following instructions could result in serious injury or death.

b. The word "CAUTION" entered before procedures means that the equipment involved may be damaged if those procedures are not observed.

c. "NOTE" is used to add emphasis to essential material which follows it.

Some examples of the way these standard precautionary terms are highlighted are shown in figure 4-4.

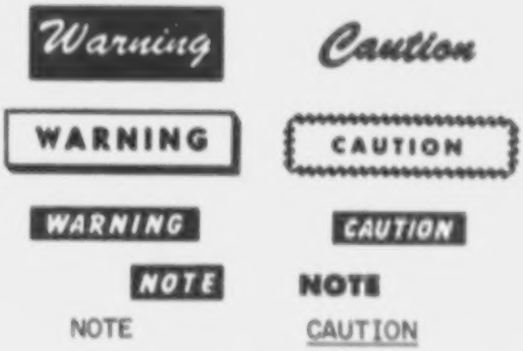


Figure 4-4. Precautionary signs used in TOs.

Exercises (084):

1. List three precautionary signs used in technical orders.

2. What could be the result of disregarding a WARNING in a TO?

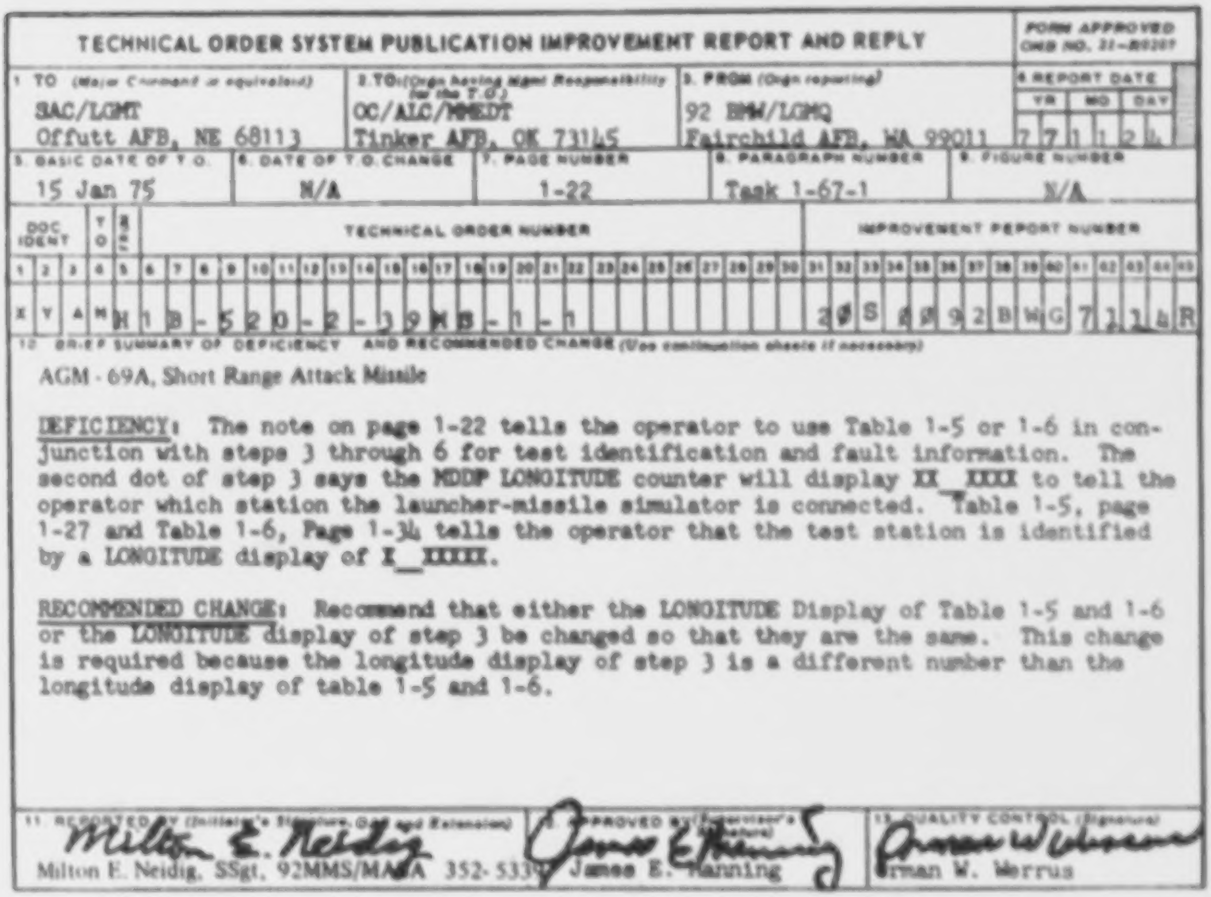
085. Determine the type of error in a TO that requires the submission of a Technical Order Improvement Report, and identify the approving office and the command that takes action to correct the error.

Errors in TOs. The maintenance specialist, the TO user, you—make the final verification of the accuracy of the TOs you use. When you are doing your job and you find an error in maintenance procedures, terminology, or any deficiency in the TO, you should do something to correct it. This is done by submitting an AFTO Form 22, Technical Order Improvement Report and Reply, shown in figure 4-5.

The term "deficiency" denotes an error or defect that changes the meaning of instruction. It could be insufficient information that prevents you from adequately performing a task or function. Deficiency does not include minor errors of a nontechnical nature, for example, misspelled words, typographical errors, and improper sequencing of pages. An AFTO Form 22 is initiated by the person who discovers the deficiency. Your shop supervisor should have a supply of AFTO Forms 22, and will help you fill one out properly. The shop supervisor is required to verify that the deficiency is valid and important enough to be reported. The report is then sent to Quality Control (QC) to be logged and approved.

Quality Control will also verify that the deficiency or error exists, that your recommendation will correct the condition, and that the report is filled out completely and properly. Identify the deficiency, tell why it should be changed, and then tell exactly the way you think it should be corrected. QC will advise and help you in preparing the report.

QC will submit the report to the MAJCOM, where it



TECHNICAL ORDER SYSTEM PUBLICATION IMPROVEMENT REPORT AND REPLY

FORM APPROVED OMB NO. 21-R0207

1. TO (Major Command or equivalent): SAC/LGMT, Offutt AFB, NE 68113

2. TO: (Orgn having Mgmt Responsibility for the T.O.): OC/ALC/MMEDT, Tinker AFB, OK 73145

3. FROM (Orgn reporting): 92 BMW/LGMQ, Fairchild AFB, WA 99011

4. REPORT DATE: YR 77 MO 11 DAY 24

5. BASIC DATE OF T.O.: 15 Jan 75

6. DATE OF T.O. CHANGE: N/A

7. PAGE NUMBER: 1-22

8. PARAGRAPH NUMBER: Task 1-67-1

9. FIGURE NUMBER: N/A

DOC. IDENT: X Y A

T.O.: M

TECHNICAL ORDER NUMBER: H 1 B - 5 2 0 - 2 - 3 9 M B - 1 - 1

IMPROVEMENT REPORT NUMBER: 2 0 S 0 0 9 2 B W G 7 1 1 4 R

10. BRIEF SUMMARY OF DEFICIENCY AND RECOMMENDED CHANGE (Use continuation sheets if necessary)

AGM - 69A, Short Range Attack Missile

DEFICIENCY: The note on page 1-22 tells the operator to use Table 1-5 or 1-6 in conjunction with steps 3 through 6 for test identification and fault information. The second dot of step 3 says the MDDP LONGITUDE counter will display XX_XXXX to tell the operator which station the launcher-missile simulator is connected. Table 1-5, page 1-27 and Table 1-6, Page 1-34 tells the operator that the test station is identified by a LONGITUDE display of X_XXXXX.

RECOMMENDED CHANGE: Recommend that either the LONGITUDE Display of Table 1-5 and 1-6 or the LONGITUDE display of step 3 be changed so that they are the same. This change is required because the longitude display of step 3 is a different number than the longitude display of table 1-5 and 1-6.

11. REPORTED BY (Initiator's Signature, Grade and Extension): Milton E. Neidig
Milton E. Neidig, SSgt, 92MMS/MAMA 352-5339

12. APPROVED BY (Supervisor's Signature): James E. Manning

13. QUALITY CONTROL (Signature): Orman W. Werrus

Figure 4-5. AFTO Form 22 (upper half of form)

will either be approved and forwarded to the appropriate Air Force Logistics Command (AFLC) depot, or disapproved and returned to you with the reason for disapproval.

The AFTO Form 22 is submitted in one of three priorities according to safety and mission impact—emergency, cover letter, or routine. AFLC acts on emergency reports within 48 hours of receipt. Action is taken within 30 days on cover letter reports and within 90 to 180 days on routine reports. You will normally be informed of the action taken on reports you submit, but replies on approved routine reports are not necessary.

It is part of your job and your responsibility to report any TO deficiency. Acceptance of such responsibility is one of the prime considerations for promotion and career progression.

Exercises (085):

1. While using a technical order, you find what you believe is an error because step 13 required external power to be disconnected; step 14 required a test set to be connected; step 15 applied external power; step 16 pulled circuit breakers A7, A9, and A10 (note failure to pull circuit breakers will cause equipment damage if power is applied); and steps 17 through 19 failed to operate properly. Should you submit a deficiency report on this type error? Why?

2. Which major command processes deficiency reports that are submitted?

3. Name the maintenance branch that will assist you in submitting deficiency reports.

4-3. Illustrated Parts Breakdown (IPB) TOs

Although they were described briefly under aircraft technical manuals, the use of IPBs is a necessary part of your job and needs to be covered in more detail. IPBs give such information as part number, nomenclature, and units per assembly. They also give a brief description of each part, identify which series of the aircraft each part is used on, and tell who manufactures each part. Some of them even give the stock number of the frequently used parts.

Assume that the reset knob on the AAU-19 altimeter is cracked and needs to be replaced. You need to know how to get either a new altimeter or a new knob. Here is where the part numbering and identification system in the illustrated parts breakdown (IPB) can help you. The IPB of the aircraft will give you the part number and description of the altimeter. You can then find its stock number listed in Air Force supply stock lists. The IPB of the altimeter will give you the part number and description of the knob. That part number, too, can be cross-referenced to a stock number. Now you have enough information to order either the altimeter or the knob.

Illustrated parts breakdown technical orders are usually divided into four sections. We will discuss each section individually.

086. State the type of information in Section I of the IPB; and, for stated conditions, give the immediate step for using the IPB.

Section I—Introduction. This section gives information that you must know in order to use the TO properly. For example, it explains the use of codes, designators, etc., used in the major sections of the TO. The introduction also contains other pertinent information. For example, it gives related TOs to be used in conjunction with the particular IPB. Vendors' names and addresses and engineering change proposals are also given. Any time you are going to use a particular IPB for the first time, be sure to read the introduction. The introduction normally includes illustrations and instructions that show how to use the IPB. Figures 4-6 and 4-7 show examples of such illustrations found in an IPB (TO 43D3-4-10-4-2). However, we have left off the instructions and included them in our text. We will use these instructions as we discuss the figures.

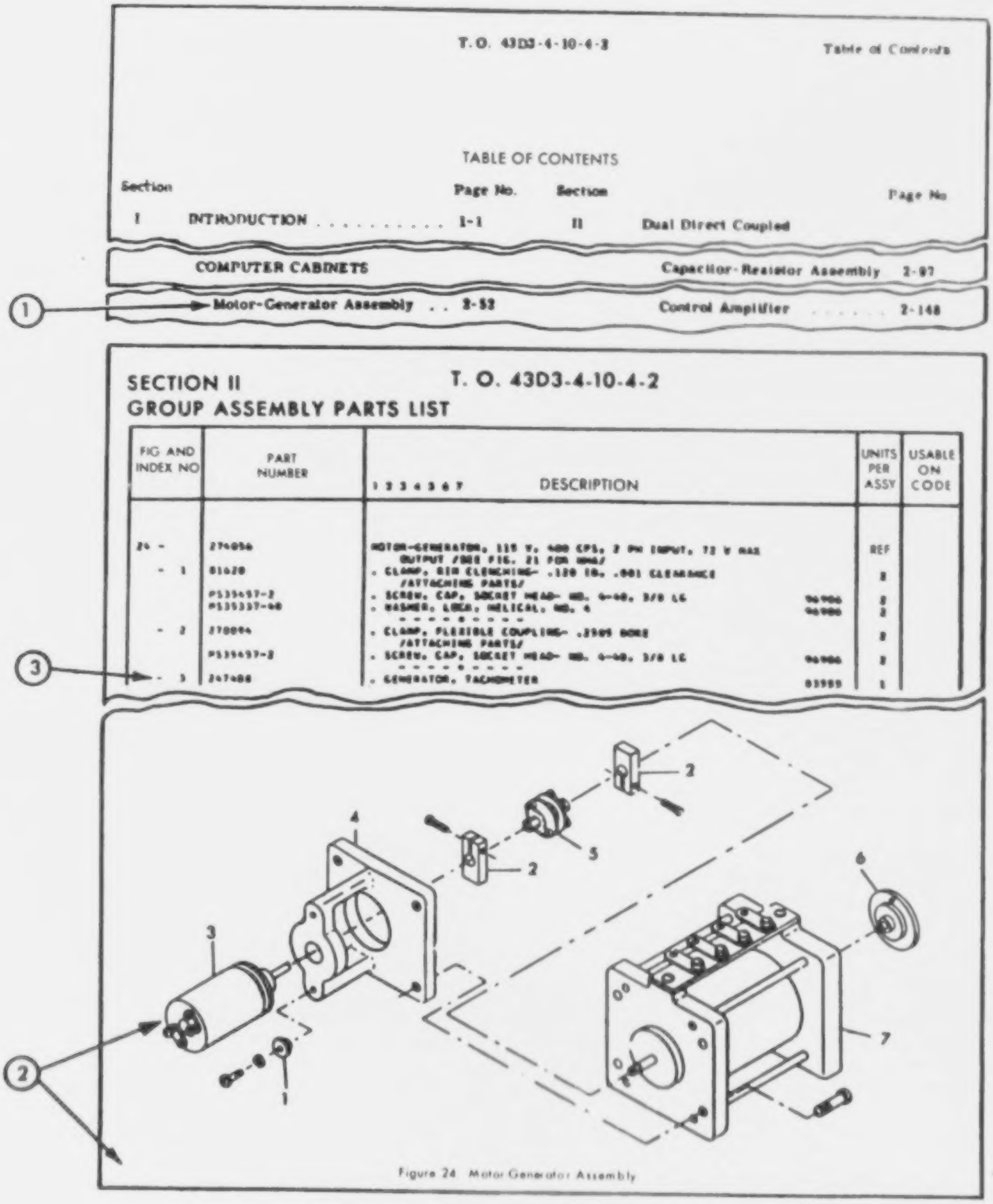
Using IPB when part number is not known. The instructions for finding specific information when the part number is not known are given below. These instructions are used in figure 4-6.

a. Determine the function and application of the part required. Turn to the table of contents and select the most appropriate title. Note the illustration page number.

b. Turn to the page indicated and locate the desired part on the illustration.

c. From the illustration, obtain the index number assigned to the part desired. Refer to the accompanying description for specific information regarding the part.

Now let's see how to use these instructions and use figure 4-6 to find the part number and nomenclature of a specific part when you do not know the part number. First, notice the circled numbers on the figure. These numbers correspond to the instructions given in each of the steps. This same procedure is followed when the instructions and figure are given in the introduction of the IPB. Step 1 tells you to determine the function and the application of the part. Remember, you are trying to find the nomenclature of the part. Once you have determined the function and application of the part, turn to the table of contents of the IPB and select the most appropriate title. Make a note of the illustration page number. In our example (fig. 4-6), the arrow from the circled "1" (corresponding to step 1) points to the "Motor-Generator Assembly—page 2-52." Step 2 instructs you to turn to the indicated page (2-52 in our example) of the IPB and locate the desired part on the illustration. The center and lower portions of figure 2-2 are excerpts from page 2-52 of the IPB. Notice that one of the arrows from the circled "2" points to the unit identifier by the number "3." We know that this is the unit we are trying to identify because



T.O. 43D3-4-10-4-2 Table of Contents

TABLE OF CONTENTS

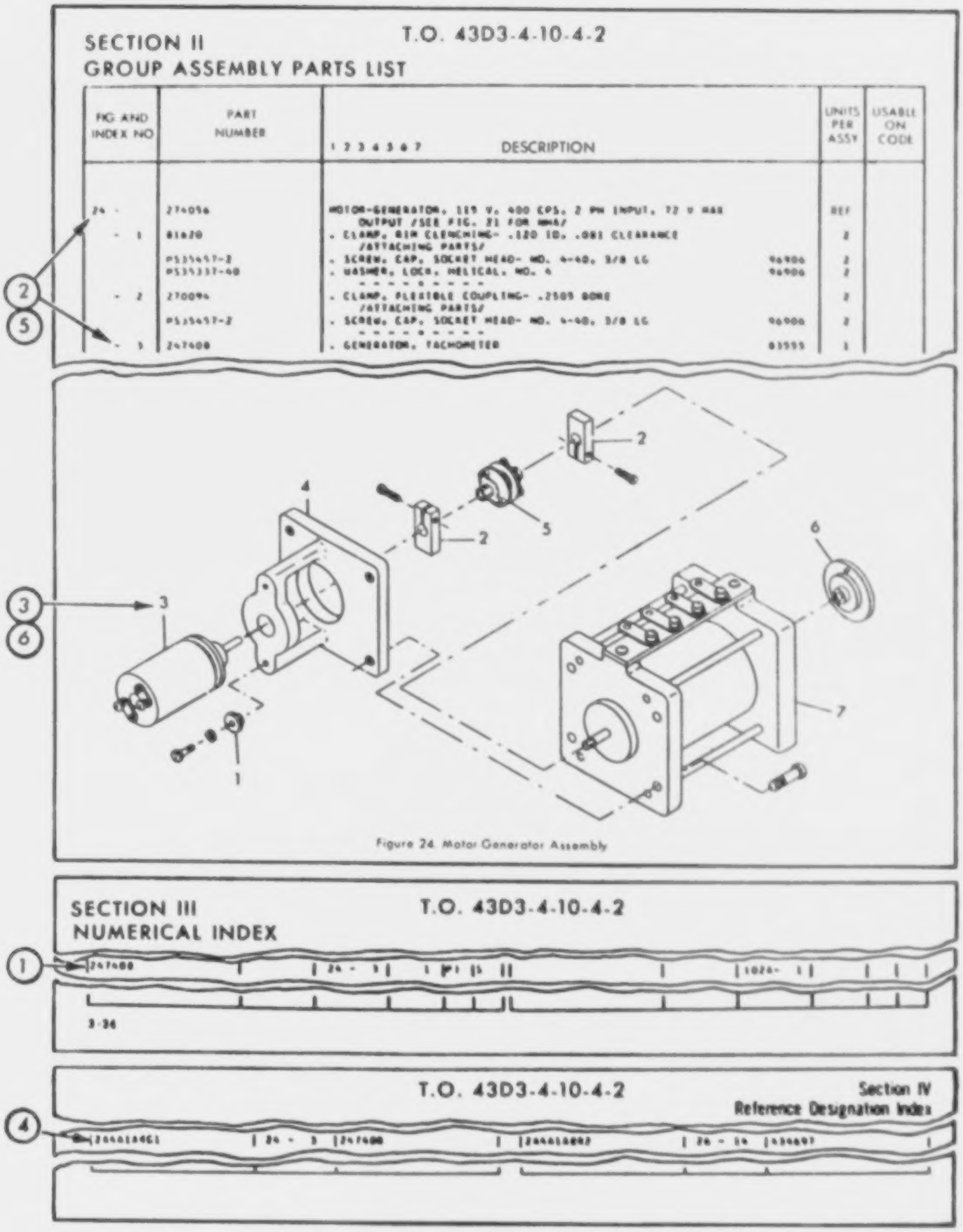
Section		Page No.	Section		Page No
I	INTRODUCTION	1-1	II	Dual Direct Coupled	
	COMPUTER CABINETS			Capacitor-Resistor Assembly	2-97
	Motor-Generator Assembly . .	2-52		Control Amplifier	2-148

SECTION II T. O. 43D3-4-10-4-2
GROUP ASSEMBLY PARTS LIST

FIG AND INDEX NO	PART NUMBER	1 2 3 4 5 6 7 DESCRIPTION	UNITS PER ASSY	USABLE ON CODE
24 -	274056	MOTOR-GENERATOR, 115 V, 400 CPS, 2 PH INPUT, 72 V MAX OUTPUT /SEE FIG. 21 FOR NHA/	REF	
- 1	81620	. CLAMP, AIR CLENCHING- .120 IN. .001 CLEARANCE /ATTACHING PARTS/	2	
	MS35457-2	. SCREW, CAP, SOCKET HEAD- NO. 4-40, 3/8 LG 96906	2	
	MS35337-40	. WASHER, LOCK, HELICAL, NO. 4 96906 - - - - * - - - -	2	
- 2	270094	. CLAMP, FLEXIBLE COUPLING- .2505 BORE /ATTACHING PARTS/	2	
	MS35457-2	. SCREW, CAP, SOCKET HEAD- NO. 4-40, 3/8 LG 96906 - - - - * - - - -	2	
- 3	247408	. GENERATOR, TACHOMETER 03959	1	

Figure 24 Motor Generator Assembly

Figure 4-6. How to use IPB when P/N is not known.



SECTION II
GROUP ASSEMBLY PARTS LIST

T.O. 43D3-4-10-4-2

FIG AND INDEX NO	PART NUMBER	1 2 3 4 5 6 7 DESCRIPTION		UNITS PER ASSY	USABLE ON CODE
24 -	274056	MOTOR-GENERATOR, 115 V, 400 CPS, 2 PH INPUT, 72 V MAX OUTPUT /SEE FIG. 21 FOR NHA/		REF	
- 1	81620	. CLAMP, RIM CLENCHING- .120 ID, .081 CLEARANCE /ATTACHING PARTS/		2	
	MS35457-2	. SCREW, CAP, SOCKET HEAD- NO. 4-40, 3/8 LG	96906	2	
	MS35337-40	. WASHER, LOCK, HELICAL, NO. 4 - - - - - * - - - -	96906	2	
- 2	270094	. CLAMP, FLEXIBLE COUPLING- .2505 BORE /ATTACHING PARTS/		2	
	MS35457-2	. SCREW, CAP, SOCKET HEAD- NO. 4-40, 3/8 LG - - - - - * - - - -	96906	2	
- 3	247400	. GENERATOR, TACHOMETER	03555	1	

Figure 24. Motor Generator Assembly

SECTION III
NUMERICAL INDEX

T.O. 43D3-4-10-4-2

247400		24 - 3							1026- 1			

3-24

T.O. 43D3-4-10-4-2

Section IV
Reference Designation Index

2A4A1A4G1	24 - 3	247400	2A4A1A8R2	26 - 14	434697

Figure 4-7. How to use IPB when P/N is known.

FIG. AND INDEX NO	PART NUMBER	1 2 3 4 5 6 7 DESCRIPTION		UNITS PER ASSY	USABLE ON CODE
24 -	274056	MOTOR-GENERATOR, 115 V, 400 CPS, 2 PH INPUT, 72 W MAX OUTPUT /SEE FIG. 21 FOR NHA/		REF	
- 1	81620	. CLAMP, RIM CLENCHING- .120 ID, .001 CLEARANCE /ATTACHING PARTS/		2	
	MS35457-2	. SCREW, CAP, SOCKET HEAD- NO. 4-40, 3/8 LG	96906	2	
	MS35337-40	. WASHER, LOCK, HELICAL, NO. 4 - - - - * - - - -	96906	2	
- 2	270094	. CLAMP, FLEXIBLE COUPLING- .2505 BORE /ATTACHING PARTS/		2	
	MS35457-2	. SCREW, CAP, SOCKET HEAD- NO. 4-40, 3/8 LG - - - - * - - - -	96906	2	
- 3	247408	. GENERATOR, TACHOMETER	83555	1	
- 4	274055	. ADAPTER, MOTOR TO GENERATOR- 7 V, 1000 RPM /ATTACHING PARTS/		1	
	MS35457-16	. SCREW, CAP, SOCKET HEAD- NO. 8-32, 5/8 LG	96906	4	
	MS35337-42	. WASHER SPRING STEEL LOCK NO. 8 - - - - * - - - -	96906	4	
- 5	844E-40E	. COUPLING,SHAFT, FLEXIBLE- SPLIT HUB, 0.1200 AND 0.1565 IN. BORE	99934	1	
- 6	272002	. COUPLING HALF, DISK, 1/2 SWEEP, TAPERED BORE		1	
- 7	FPE25-155-1	. MOTOR, CONTROL, 115/115 V, 400 CPS, 7 W OUTPUT	17771	1	

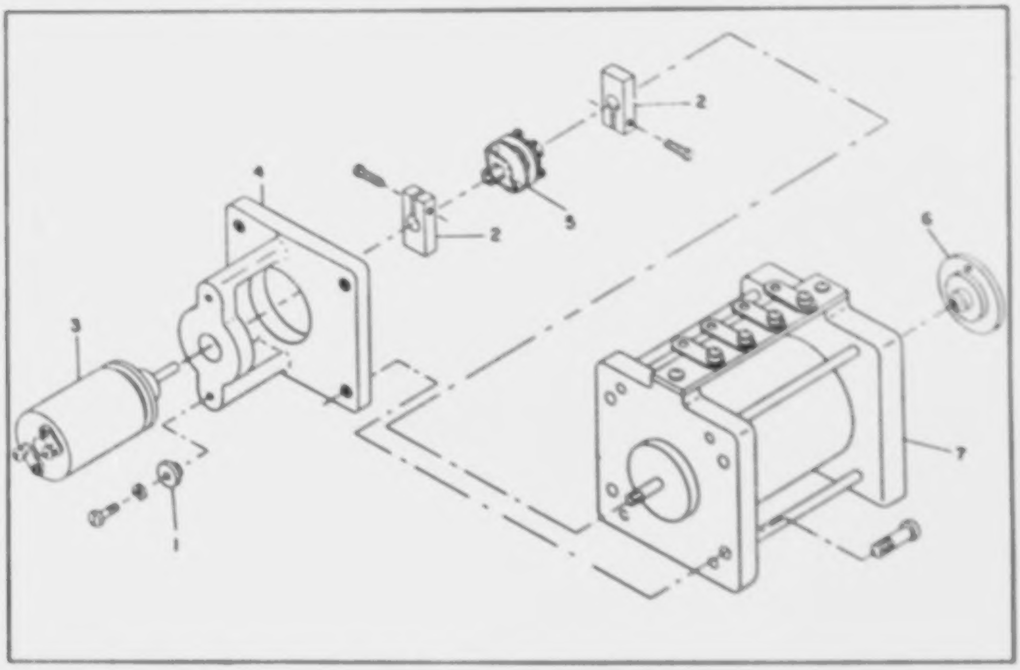


Figure 4-8. IPB - Group Assembly Parts List

of seeing it on the equipment. Now go to step 3. This step instructs you to obtain from the illustration the index number assigned to the part. In our example, the index is 3. Also make a note of the figure number on which the parts are illustrated (fig. 24). Using the index number and figure number, refer to the accompanying description in the Group Assembly Parts List for the index number. The circled "3" points to the index number "3." Now you can determine the part number and description of the part in question.

Using IPB when part number is known. The instructions for finding specific information when the part number is known are given below. Remember, these instructions will normally be included on the illustration in the introduction (Section I) of the IPB technical order. The following instructions are used with figure 4-7.

a. When the part number is known, refer to Section III, Numerical Index. Locate the part number and note the figure and index number assigned to the part number.

b. Turn to the figure number indicated in Section II and locate the index in the accompanying Group Assembly Parts List.

c. If a pictorial representation of the part or its location is desired, refer to the same index number on the accompanying illustration.

d. When the reference designation is known, refer to Section IV, Reference Designation Index. Locate the reference designation and note the figure and index number and the part number assigned.

e. Refer to the figure and index number in the Group Assembly Parts List.

f. If a pictorial representation of the part or its location is desired, refer to the same index number on the accompanying illustration. You use the above instructions in the same manner as previously described for finding information for a part when the part number is not known. Read the above steps and refer to the corresponding circled number in figure 4-6 to learn how to use the figure and instructions.

Exercises (086):

1. What type of information is found in the introduction section of the IPB?

2. How do you begin finding specific information about a part when you do not have the part number?

3. How do you begin finding specific information about a part when you know the part number?

087. Name the five columns listed in the Group Assembly Parts List, and give the purpose of various sections, columns, and notations.

Section II—Group Assembly Parts List. This section of the IPB consists of a breakdown list of major assemblies accompanied by an illustration of the major assembly breakdown. Figure 4-8 shows the complete page from the Group Assembly Parts List that we used in figures 4-6 and 4-7. We will discuss the organization of this section by interpreting the information entered in each of its five columns: (1) Figure and Index Number, (2) Part Number, (3) Description, (4) Units per Assembly, and (5) Usable on Code.

Refer to the Figure and Index Number column. As you learned previously, the figure numbers in the Group Assembly Parts List correspond to the number of an illustration. The index number identifies the part shown in the illustration. In our example, the figure is on the same page as the parts listing. However, in other portions of the Group Assembly Parts List, you may find the figure on a separate page.

The Part Number column contains the part number that may be the manufacturer's part number or a standard part number. Manufacturer's part numbers are usually assigned in straight numerical order. Standard part numbers normally have an alphabetical prefix. These parts are used throughout the Air Force on various equipment. Letters and designators of some of the common prefixes are as follows:

- AN—Air Force-Navy standards.
- LS—Contractor or manufacturers' standards.
- MS—Military standards.
- NAS—National aircraft standards.

Notice in figure 4-8 that the Description column has indentations, each identified by dots preceding the assembly listing. These dots are arranged in as many as seven columns identified by numbers. These numbers are shown to the left of the word "DESCRIPTION." The indentations show the relationship of the component to the complete assembly. Quite often, you will want to determine the next "higher" assembly for a part of an assembly. Note the dot column in which the first word of the nomenclature begins. The first item directly above and one column to the left is the next higher assembly. An example of the next higher assembly relationship, indicated by the indentation method, is as follows:

1 2 3 4 5 6 7 DESCRIPTION FIGURE TITLE
.Assembly
..Subassemblies
...Detail parts of subassemblies
....Sub-subassemblies
.....Detail parts of subassemblies

Some of the cross-references that you will see following the description of parts numbers are abbreviated as follows:

a. The notation "/SEE FIG—FOR NHA/" indicates the figure where the next higher assembly is shown. (For example, this abbreviation is shown in the second line under "Description" in fig. 4-8.)

b. The notation "/SEE FIG—FOR BRKDN/" indicates that its component parts are shown in further detail on the figure noted.

c. The notation "/SEE FIG—FOR FURTHER BRKDN/" indicates that its component parts are shown in additional detail on the figure noted.

d. The notation "/SEE FIG—FOR FURTHER ILLUSTRATION/" indicates that the part is illustrated to clarify or continue a system on the figure noted.

e. The notation "/SEE FIG—/" is used for cross-referencing purposes when not covered by a specific phrase.

f. The notation "/SEE TO—/" refers to the supplemental illustrated parts breakdown covering that individual part.

g. The notation "/NHA—/" indicates the next higher engineering assembly of that part.

h. Finally, the number at the right-hand portion of the Description column is the vendor's code. This code number identifies the source of the part.

The Units per Assembly column reflects the quantity of parts required on the next higher assembly. You may find the abbreviation "AR" in this column. This indicates that no specific number can be given; simply use as many as required. The abbreviation "REF," shown in figure 4-8, indicates that the units per assembly will be found on another figure.

The Usable-on Code column is shown in the extreme right portion of figure 4-8. There is no code shown in our example. The code is composed of either a letter or letter-number combination and indicates limited usage of a part such as applies to a specific model of the equipment.

Exercises (087):

1. What section of the IPB usually contains a general view of the equipment?

2. What section of the IPB contains a breakdown list of the major assemblies of the equipment?

3. Name the five columns listed in the Group Assembly Parts List.

4. What is the purpose of the Usable On Code column of Section II of the IPB?

5. What do the indentations in the Description column show?

6. What does "/SEE FIG. 21 FOR NHA/" in the Description column in figure 4-8 indicate?

7. What does the Units per Assembly column indicate?

088. Give the purpose of Section III in the IPB.

Section III—Numerical Index. Excerpts from a page (3-34) of a numerical index are shown in the lower section of figure 4-7. The numerical index lists all part numbers (left-hand column) appearing in the Group Assembly Parts List in alphanumerical sequence. These part numbers correspond to the part numbers shown in the Part Number column of the Group Assembly Parts List. Therefore, you can cross-reference a part number listed in the numerical index to the part number listed in the Group Assembly Parts List. An example of this was previously given under the heading "Using IPB when part number is known." Notice that the entries in the Figure and Index Number column (third from the left) in the numerical index correspond to the Figure and Index Number column of the Group Assembly Parts List. The remaining columns in the numerical index are used primarily by supply personnel and thus will not be discussed.

Exercise (088):

1. What is the purpose of Section III of the IPB?

089. State the purpose of Section IV in the IPB.

Section IV—Reference Designation Index. Portions of a Reference Designation Index are shown in the lower section of figure 4-7. The reference designation is the number given on a schematic that identifies the cabinet, shelf, drawer, diode, resistor, tube, etc., for a particular unit. This index provides a rapid means of cross-referencing between TO schematic wiring diagrams and the figure and index numbers in the Group Assembly Parts List (Section II). The reference designations are arranged in numerical sequence and cross-referenced to figure, index number, and part number, as shown in figure 4-8.

Exercise (089):

1. What is the purpose of Section IV of the IPB?

4-4. Wiring Diagrams

Like the IPB manuals, wiring diagram manuals provide highly specialized information in regard to electrical and electronic circuits. Finding and identifying a broken wire which is causing a system to malfunction can be an awesome and overwhelming job when you consider the number of different systems, different wires, and millions of feet of wiring used in a modern aircraft. The proper use of a wiring diagram will make such a task relatively simple.

These manuals were not previously described under aircraft technical manuals because wiring diagrams, per se, are not identified by a specific kind of TO number as are IPB and inspection requirements manuals. Wiring diagram manuals are included in the dash two (-2) maintenance manual category.

Wiring diagram manuals usually have an introduction and three sections of technical information. We will discuss each individually.

090. State the purpose of wiring diagram manuals.

Use of Wiring Diagram Manuals. These manuals must be used in conjunction with troubleshooting diagrams or charts, as they do not show the internal wiring of components. When a maintenance problem has been isolated to the associated wiring, these manuals are used to identify the specific wire and isolate the problem to a specific section or part of the wire.

To troubleshoot wiring, use the system maintenance manual to isolate the problem down to an electrical connector or pin on a component of the system. Note the electrical reference designation number of the connector and the pin letter of the malfunctioning circuit. Refer to Section I of the wiring diagram manual, and locate the reference designation and pin letter. Then turn to the referenced drawing number in Section III. Using the diagram or drawing of the circuit, you can determine the number of each wire or segment of wire, splice areas, switches, terminal blocks, relays, etc., that you may need to check.

The introduction of each wiring diagram manual will give the purpose and scope of application as well as all necessary information on how to use the manual. It will include the abbreviations used, standard symbols and peculiar symbols used, an explanation of wire numbers, circuit function letters, etc. The introduction must be referred to in order to determine if switches or relay contacts are shown in the open or closed position.

Exercises (090):

1. How must wiring diagram manuals be used?

2. Why must wiring diagram manuals be used when a maintenance problem has been isolated to the associated wiring?

3. Why are reference designators used in systems maintenance manuals and troubleshooting diagrams?

4. Why should you read the introduction before attempting to use a wiring diagram manual?

091. Interpret wire numbers.

Wire Numbers. Each wire in an aircraft is coded with a number to identify the wire. For example, 2E122B18N may be used to identify a wire in a tachometer system. The first number (unit number) is used to identify the system when there is more than one of that type of system. In the example given, the aircraft has at least two engines with identical tachometer systems. The "E" in the above example is the circuit function letter. In this case, it tells you that this particular wire is part of an engine instrument system. The circuit function letter "E" is used to identify all engine instrumentation. The specific system is not identified in the wire number. Other circuit function letters which apply to instruments are "F" for flight instruments, "D" for instruments other than engine and flight, "L" for lighting circuits, "V" for DC power, and "X" for AC power. TO 1-1A-14 and the introduction to each wiring diagram manual has a complete listing of circuit function letters.

The next three digits (122) identify the number of the wire. The wire number, consisting of one or more digits, is used to differentiate between wires in a circuit. A different number is used for each wire which does not have a common terminal or connection with another wire. Wires with the same circuit function which do have a common terminal, connection, or junction have the same wire number but different segment letters. Wire segments are lettered in alphabetical sequence. The letter "A" identifies the first segment of each circuit starting at the power source. Therefore, the letter "B" in our example tells us that this is the second segment of wire from the power source. The letters "I" and "O" are not used in order to prevent confusion with the numbers 1 and 0. Double letters, "AA," "AB," "AC," "BB," etc., are used when more than 24 segments are required.

The numbers following the segment letter identify the size of the wire or cable. The "18" in our example indicates 18-gauge wire. For coaxial cables and thermocouple wires, the wire size number is not included. For thermocouple wires, a dash (-) is used in place of the wire-size number.

The last letter usually will not be included in that it identifies a ground, phase, or thermocouple lead. The letter "N," as in our example of 2E122B18N, is a suffix used to identify any wire or cable which completes a circuit to ground. The phase letter "A," "B," or "C" is the suffix used to identify the phase of wires that are in the three-phase power distribution wiring of AC systems. The phase letter "V" is used to identify ungrounded wires in a single-phase system. The following suffixes are used to identify the type of wire used in a thermocouple circuit.

CHROM—Chromel
ALML—Alumel
IRON—Iron
CONS—Constantan
COP—Copper

Exercises (091):

1. If you were checking the continuity of a wire with the number 3E124C20, on which engine would you be troubleshooting an instrument system?

2. The "F" in wire number 2F166A20A identifies that wire as part of which group of instruments?

3. What does the "A" mean in wire number 1F166B20A?

4. What size of wire should you use to replace a damaged section of a wire numbered 4E018C20?

5. How would the third segment of wire from the power source be identified if the first segment was marked with wire number L266A20?

092. State the purpose of Section I of a wiring diagram manual.

Section I—Designation Cross-Reference. This section provides a complete listing of every switch, terminal block, relay, connector, splice area, etc. It may include an equipment item list which gives part numbers for the reference designators. It is also used to locate information in Sections II and III. As in the dash four (-4), the reference designations are arranged in numerical sequence and cross-referenced to figure or drawing number.

Exercise (092):

1. What is the purpose of the Designation Cross-Reference section?

093. State the purpose of Section II of a wiring diagram manual.

Section II—Location Drawings. This section contains drawings which show the location of all items listed in the manual. In some of the older manuals, station numbers are used in lieu of this section.

Drawings are arranged by section of the aircraft. The first drawing is normally used as a pictorial index of the sections of the aircraft. Reference designators given on more than one drawing will be coded on the drawing which best shows the item for maintenance purposes. For those wiring diagram manuals that do not contain location drawings, you will have to use the IPB to see where the items are positioned on the aircraft.

Exercises (093):

1. What is the purpose of the location drawings contained in wiring diagram manuals?

2. What other references may serve the same purpose as wiring diagram location drawings?

094. State the purpose of Section III of the wiring diagram manual.

Section III—Wiring Diagrams. This section contains information on the aircraft wiring and shows complete wiring connections from component to component. It utilizes all of the abbreviations, symbols, and reference designators to provide relatively easy to read diagrams for each system used on an aircraft. Identical systems are not duplicated, but more than one system may be shown in one figure in order to reflect the different wire numbers for each system. A wiring diagram is normally the only reference that provides wire numbers. Most wiring diagram manuals have a table of contents at the beginning of this section that permits you to look up the figure or drawing numbers according to system nomenclature. The standard symbols used in these drawings will be explained in the *Electronic Principles* volume of this CDC.

Exercises (094):

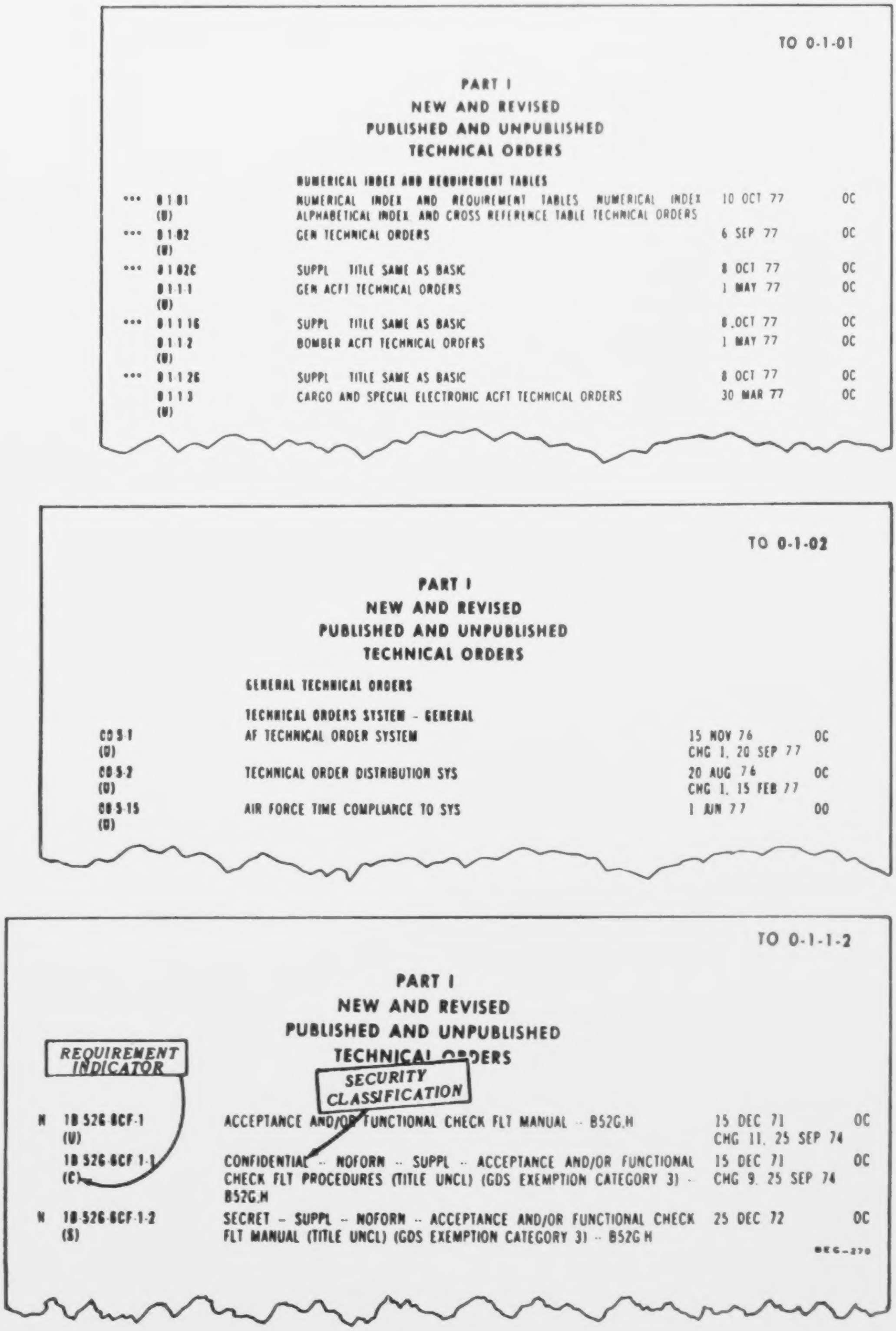
1. What is the purpose of wiring diagrams?

2. What information is provided by wiring diagrams that is not normally provided anywhere else?

4-5. Maintaining Technical Order Files

Although the indexes list many publications, it would be impractical for a single organization in the field to obtain all of the publications. Therefore, only limited files of TOs are authorized for Air Force installations and activities. Each shop, section, and organization has a limited file of TOs that are needed for that shop, section, or organization to accomplish its assigned mission.

Your shop chief must assign one or two people in your



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                                                                    TO 0-1-01

                                   PART I
                              NEW AND REVISED
                        PUBLISHED AND UNPUBLISHED
                             TECHNICAL ORDERS

                    NUMERICAL INDEX AND REQUIREMENT TABLES
*** 0-1-01          NUMERICAL INDEX AND REQUIREMENT TABLES NUMERICAL INDEX  10 OCT 77      OC
    (U)             ALPHABETICAL INDEX AND CROSS REFERENCE TABLE TECHNICAL ORDERS
*** 0-1-02          GEN TECHNICAL ORDERS                                    6 SEP 77       OC
    (U)
*** 0-1-02C         SUPPL   TITLE SAME AS BASIC                             8 OCT 77       OC
    0-1-1-1         GEN ACFT TECHNICAL ORDERS                               1 MAY 77       OC
    (U)
*** 0-1-1-1S        SUPPL   TITLE SAME AS BASIC                             8.OCT 77       OC
    0-1-1-2         BOMBER ACFT TECHNICAL ORDFRS                            1 MAY 77       OC
    (U)
*** 0-1-1-2S        SUPPL   TITLE SAME AS BASIC                             8 OCT 77       OC
    0-1-1-3         CARGO AND SPECIAL ELECTRONIC ACFT TECHNICAL ORDERS      30 MAR 77      OC
    (U)
```

```
                                                                    TO 0-1-02

                                   PART I
                              NEW AND REVISED
                        PUBLISHED AND UNPUBLISHED
                             TECHNICAL ORDERS

                    GENERAL TECHNICAL ORDERS

                    TECHNICAL ORDERS SYSTEM - GENERAL
00-5-1              AF TECHNICAL ORDER SYSTEM                   15 NOV 76          OC
(U)                                                             CHG 1, 20 SEP 77
00-5-2              TECHNICAL ORDER DISTRIBUTION SYS            20 AUG 76          OC
(U)                                                             CHG 1, 15 FEB 77
00-5-15             AIR FORCE TIME COMPLIANCE TO SYS            1 JUN 77           00
(U)
```

```
                                                                    TO 0-1-1-2

                                   PART I
                              NEW AND REVISED
                        PUBLISHED AND UNPUBLISHED
                             TECHNICAL ORDERS

N  1B-52G-6CF-1      ACCEPTANCE AND/OR FUNCTIONAL CHECK FLT MANUAL -- B52G,H     15 DEC 71          OC
   (U)                                                                           CHG 11, 25 SEP 74
   1B-52G-6CF-1-1    CONFIDENTIAL -- NOFORN -- SUPPL -- ACCEPTANCE AND/OR FUNCTIONAL  15 DEC 71     OC
   (C)               CHECK FLT PROCEDURES (TITLE UNCL) (GDS EXEMPTION CATEGORY 3) -   CHG 9, 25 SEP 74
                     B52G,H
N  1B-52G-6CF-1-2    SECRET -- SUPPL -- NOFORN -- ACCEPTANCE AND/OR FUNCTIONAL CHECK  25 DEC 72     OC
   (S)               FLT MANUAL (TITLE UNCL) (GDS EXEMPTION CATEGORY 3) -- B52G,H
```

Figure 4-9. NI&RT.

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shop the primary responsibility of maintaining your TO file. Even if this TO monitor duty is not given to you, you need to be familiar with the maintenance and upkeep of this file.

Your organization, unless it is just being activated, will have a TO file on hand. We will assume that there is a limited file and will discuss the means of adding new TOs, deleting the ones not required, or changing the quantity authorized. We will not discuss the initial setup of a new file. This is a rare occasion; but, should it occur, the detailed procedure is provided in TO 00-5-2.

095. State the purpose of NI&RTs, and specify the part or area used to locate specified information in the NI&RT.

Numerical Indexes and Requirements Tables (NI&RTs). NI&RTs show the status of TOs and provide a basis for determining distribution and requisition requirements and updating TO files and records. Some examples of NI&RTs are shown in figure 4-9.

Each NI&RT covers a TO category. Some NI&RTs are divided into separate sections covering related groups of TOs within a category. Some NI&RTs are for special purposes only and are not applicable to all TODOs (Technical Order Distribution Office).

Air Force activities requiring continued distribution of TOs need TOs 0-1-01 and 0-1-02. These are the indexes discussed earlier. TO 0-1-01 lists NI&RTs, and the preface contains data applicable to all NI&RTs. TO 0-1-02 lists general TOs, including TO 00-5-1 and 00-5-2.

Part I. NI&RTs are published in two parts. (Refer to fig. 4-9 while reading the following.) Part I lists active, published TOs and TCTOs; new basic TOs in preparation, except TCTOs; and active TCTO series. It contains the following elements:

a. Text headers—the title of TO series.

b. TCTO series—identified by the symbol "S."

c. TO symbols—applicable symbols which appear in front of TO numbers and are explained in the preface of TO 0-1-01.

d. TO numbers—the complete number is shown for each TO and TCTO series.

e. Requirements indicators.

(1) The requirements indicator listed in Part I of NI&RTs is the proposed classification for a TO or TCTO series header. The potential classification is shown in parenthesis below the TO number, as applicable. They do not identify the actual classification or restriction of a TO. This is shown as described in *f* below.

(2) The indicators used are: U—Unclassified, C—Confidential, and S—Secret. When a restriction is applicable, it is shown following the appropriate security classification indicator as F—Formerly Restricted Data or R—Restricted Data.

(3) When a TO is listed without a requirements indicator, it means ID requirements are not to be submitted for the TO.

(4) Requirements indicators for other than the actual security classification and restriction of a TO will be deleted after a TO is published. Deleted indicators are shown in Part II (not shown in fig. 4-9) of NI&RTs by a separate entry for each indicator deleted. When an entire TO or TCTO series is deleted/cancelled/rescinded, it will be shown in Part II as a single entry without requirements indicators. When a TO is downgraded, requirements will be automatically transferred to the new lower classification.

f. Security classification. The actual security classification of classified TOs is shown as the first element in the title column. No classification is shown for unpublished TOs or for published, unclassified TOs.

g. TO titles. The title column includes the actual security classification; the type of TO, except for TCTOs; the TO title; the title classification and the general declassification schedule application for classified TOs; the equipment manufacturer's name, when applicable; and the TO applicability, as explained in the preface of TO 0-1-01. The title of TO supplements is "TITLE SAME AS BASIC," except the complete title is given when it or the applicability is different from that of the basic TO. When no title is given for a basic TO, the title is the same as the text header. The title of TCTO series is "TCTO SERIES" because the actual title is the same as the text header.

h. Dates. For published TOs, the basic date or the words "NOT DATED" are shown. The date and number of the latest change and/or technical order page supplement (TOPS) are shown beneath the basic date.

Part II. Part II is used in NI&RT supplements and in basic NI&RTs updated by revisions instead of supplements. Part II is for maintenance of TO files and records, and lists cancellation, deletion, reclassification, renumbering, and replacement and rescission actions.

Exercises (095):

1. What is the purpose of NI&RTs?

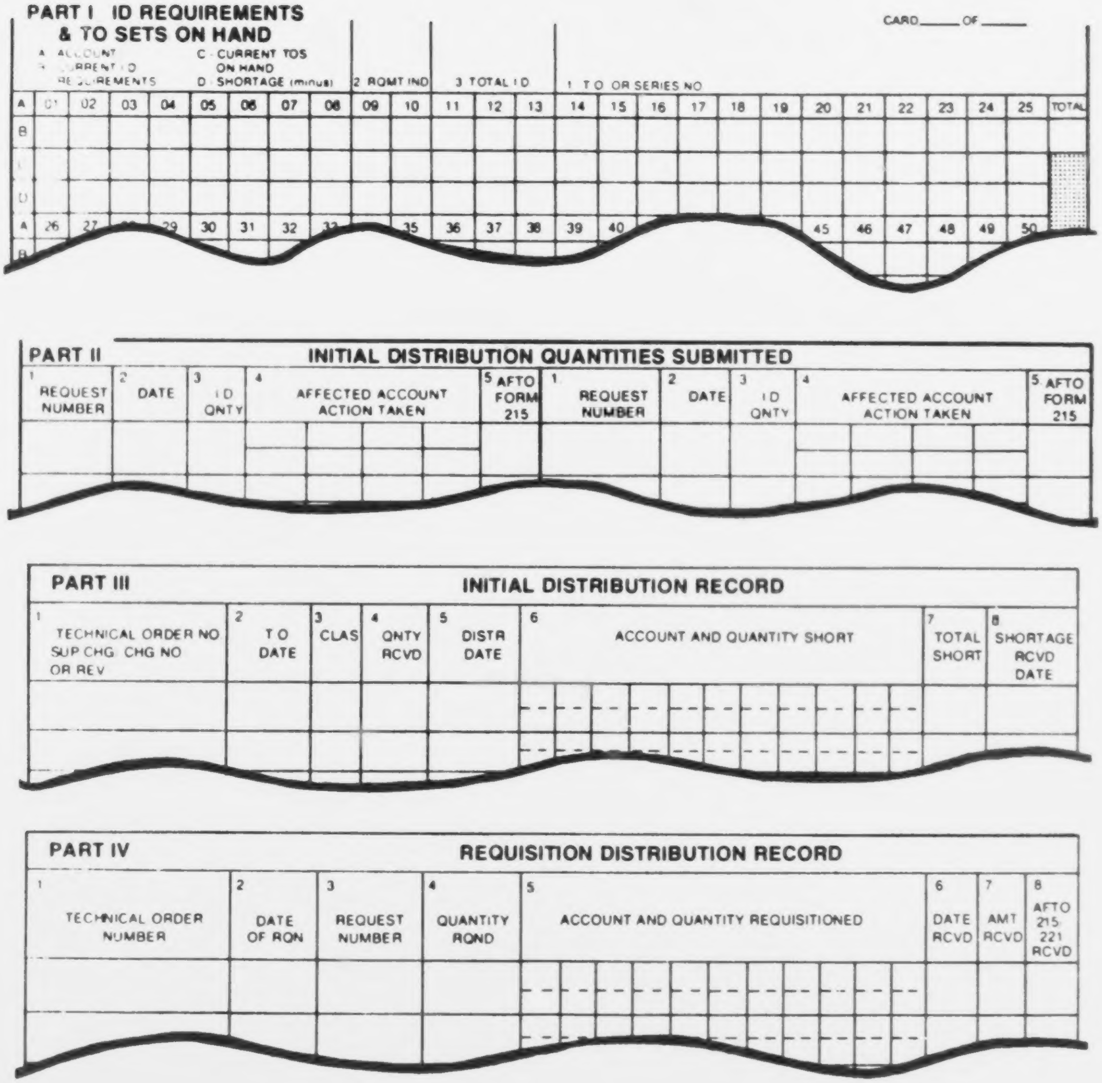
2. In what part or area are cancelled or rescinded TOs listed?

3. Where can you find out if a TO can be ordered?

4. Where is the actual security classification of a TO shown?

096. Explain the entries on the AFTO Form 110, Technical Order Distribution Record.

AFTO Form 110, Technical Order Distribution



PART I ID REQUIREMENTS & TO SETS ON HAND

A ACCOUNT
B CURRENT ID REQUIREMENTS
C CURRENT TOS ON HAND
D SHORTAGE (minus)

2 RQMT IND
3 TOTAL ID
1 T O OR SERIES NO

CARD ____ OF ____

A	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	TOTAL
B																										
C																										
D																										
A	26	27		29	30	31	32	33		35	36	37	38	39	40					45	46	47	48	49	50	
B																										

PART II **INITIAL DISTRIBUTION QUANTITIES SUBMITTED**

1 REQUEST NUMBER	2 DATE	3 ID QNTY	4 AFFECTED ACCOUNT ACTION TAKEN	5 AFTO FORM 215	1 REQUEST NUMBER	2 DATE	3 ID QNTY	4 AFFECTED ACCOUNT ACTION TAKEN	5 AFTO FORM 215

PART III **INITIAL DISTRIBUTION RECORD**

1 TECHNICAL ORDER NO SUP CHG CHG NO OR REV	2 TO DATE	3 CLAS	4 QNTY RCVD	5 DISTR DATE	6 ACCOUNT AND QUANTITY SHORT	7 TOTAL SHORT	8 SHORTAGE RCVD DATE

PART IV **REQUISITION DISTRIBUTION RECORD**

1 TECHNICAL ORDER NUMBER	2 DATE OF RQN	3 REQUEST NUMBER	4 QUANTITY RQND	5 ACCOUNT AND QUANTITY REQUISITIONED	6 DATE RCVD	7 AMT RCVD	8 AFTO 215-221 RCVD

Figure 4-10. AFTO Form 110.

Record. AFTO Forms 110 will be used to maintain a record of the TOs required, received, redistributed, and maintained when the activity maintains one or more TO files. (NOTE: We will describe the revised AFTO Form 110. If the old forms (5- x 8-inch cards) are still maintained in your section, you should acquire the new ones and convert over immediately, according to TO 00-5-2.)

The revised AFTO Form 110 is an 8- x 10-inch card, printed on both sides (see fig. 4-10). The form is designed for use in a three-ring loose-leaf binder; however, alternate filing methods are permitted. The card is divided into four parts for maintenance of TO requirements and distribution records as described below. To provide for updating entries, all entries on the form should be made in pencil. AFTO Forms 110 will be filed by TO number in alphanumeric order. When additional (continued) AFTO Forms 110 are used, they will be annotated, such as : "1 of 3." A separate AFTO Form 110 will be prepared by the activity maintaining the AFTO Forms 110 file for the following: (1) each TO, (2) each TO series listing and requirements indicator for which initial distribution or requisition requirements are submitted, and (3) for TOs on hand. The TO series-listing card may be maintained for applicable TCTO requirements. As a MAJCOM option, a separate AFTO Form 110 may be prepared for each TCTO required. Those TCTOs not required will be listed on Part III of the TCTO series card with an NR in block 5. This option may also be applied to flight safety supplements—or flight safety supplements may be recorded on an individual AFTO Form 110.

AFTO Form 110 is a four-part form: Part I, ID Requirements and TO Sets on Hand; Part II, Initial

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Distribution Quantities Submitted; Part III, Initial Distribution Record; and Part IV, Requisition Distribution Record.

Part I, ID Requirements and Sets on Hand.

Block 1—Enter the applicable basic TO number, series number, or basic NI&RT number.

Block 2—Enter the requirements indicator for the listing of the number as shown in the NI&RT. Leave blank if unclassified. If classified enter the following: C—Confidential; S—Secret; CR—Confidential, Restricted Data; CF—Confidential Formerly Restricted Data; SR—Secret, Restricted Data; SF—Secret, Formerly Restricted Data.

Block 3—Enter the total initial distribution quantity.

Block 4 (not shown in fig. 4-10)—Enter only appropriate remarks as indicated in these instructions.

Line A—Assign these numbers to identify technical order distribution accounts (TODAs), technical order distribution subaccounts (TODSs), or type IIA sub-subaccounts described in Section II of TO 00-5-2. The definition of "account," used as a collective term in this paragraph to indicate TODA, TODS, or type IIA sub-subaccounts—is determined by the level at which AFTO Form 110 is maintained. (NOTE: Technical order distribution offices (TODOs) or TODAs making redistribution will maintain current organization identification and location data for the receiving TODAs or TODSs.)

Line B—For each number assigned in line A, enter the quantity required by the TODA, TODSs, or type IIA subaccount identified by that number.

Line C—For each number assigned in Line A, enter the quantity of the current TO on hand by the TODA, TODSs, or type IIA subaccount identified by that number.

Line D—Enter minus (−) only when increment(s) of the TO on hand, by an account, are missing, such as changes, supplements, etc. (NOTE: When a minus is indicated here, the specific change, supplement, etc., must be indicated in Part III as shortage on ID received, and in Part IV as on requisition for the account. When the change, supplement, etc., is received, the minus will be erased. Do not enter quantities in this block (D). When complete sets are needed by an account, this is depicted by the difference between lines B and C).

Part II, Initial Distribution Quantities Submitted.

Block 1—Enter request number from AFTO Form 187, TODO/Technical Order Publication Requirement Table.

Block 2—Enter date request submitted.

Block 3—Enter total ID quantity submitted (from Part I, Block 3, as shown on request in ID quantity column, such as AFTO Form 187).

Block 4—Enter account affected and action taken that affected changes by account as follows:

Example 1: Account was on for 15; now wants 20.

Show: 02
+5

Example 2: Account was for 16; now reduces to 7.

Show: 02
−9

Example 3: Account was not on for 10; now wants 8.

Show: 02
+8

Block 5—Enter the notice code only when an AFTO 215 (Notification) is received on this transaction. This will indicate an AFTO Form 215 is in file relevant to initial distribution with appropriate subsequent action taken indicated thereon.

Part III, Initial Distribution Record.

Block 1—Enter the basic TO number on the first line but do not repeat it on subsequent lines. When a supplement is received, enter the suffix (for example, C, -S-1, -SS-2). When a change is received, enter "CHG," followed by the change number. When a revision is received enter "REV."

Block 2—Enter the applicable TODO, TODA, or TODS request number.

Block 3—Enter the TO classification only if different from the basic.

Block 4—Enter the quantity received. (NOTE: When the quantity received is less than indicated on the ID label, follow TO 00-5-2, Section VII, for shortage in ID and complete necessary actions.)

Block 5—Enter the date of distribution to the accounts.

Block 6—Enter the account number and quantity as follows when an account is shorted in ID:

Example: 21
1

NOTE: When more than one line is required to list all accounts shorted, use the next line and place ditto marks in Blocks 1, 2, 3, 4, and 5.

Block 7—Enter the total quantity short.

Block 8—Enter the date the shortage is received. (NOTE: In Part I, raise quantity on hand, line "C," appropriate to account and erase the minus sign in line "D" when all shortages, including requisitioned increments, have been received by the account. In Part III, appropriate entries in Blocks 1, 2, and 3 will be lined out as applicable data are rescinded or replaced. Changes will be lined out on receipt of a basic TO revision replacing them. Supplements may be lined out when replaced by a change or revision to the basic or another supplement.)

Part IV, Requisition Distribution Record.

Block 1—Do not enter TO number. When a supplement is requisitioned, enter the suffix and date of the supplement. When a change is requisitioned, enter "CHG," followed by the change number and the date of the change. When a basic TO (new or revision) is requisitioned enter "BASIC," followed by the date of the publication.

Block 2—Enter date of requisition.

Block 3—Enter the request number. If a followup is initiated on the request, enter "F" before the request number.

Block 4—Enter the total quantity requisitioned on this request.

Block 5—Enter the account number affected and the quantity for the account as follows:

Example: 26 29
4 2

Block 6—Enter the date the TO is received.

Block 7—Enter the amount received. Update Part I entries (on account lines "C" and "D") when applicable to complete sets maintained by the account. When a requisition is cancelled, enter in Part IV, Block 6, the date of cancellation and enter a "C" in Block 7.

Block 8—Enter the notice code on this transaction from the AFTO Form 215, when received. This will indicate an AFTO Form 215 is in file with annotation of subsequent action. When a partial shipment is received, enter back-ordered coding from the AFTO Form 221, ADP Requisition for Air Force Technical Order. (NOTE: Neither the requirements for initial distribution (ID) quantities nor the receipts from ID, i.e., shipments received with AFTO Form 273, Initial Distribution, or Form 274, Initial Distribution Label, are recorded in Part IV. Requirements are recorded in Part II and receipts from ID are recorded in Part III.)

Additional guidance. On new TOs the (first time) initial submittal of ID quantities for accounts, ID quantities and actions are shown on the "B" line of Part I and, therefore, need not be shown (the first time) in Block 4, Part II. Subsequent changes to ID, however, by account actions must be properly recorded in Part I and Part II. In such instances, Part I shows the latest ID requirements of the account and Part II shows the actions, by account, which cause the resulting changes. When changes in account ID requirements result in a change and transfer of TOs in the same quantity between accounts, there is no change in the total ID requirements on the AFTO Form 110 of the TODO, TODA, or TODS maintaining the record set. The account actions should be recorded in Part II as shown in the following sample for record purposes. "N/A" indicates request number is not applicable in this case and no change in ID quantities. This is in addition to changing Blocks "B" and "C" of Part I as appropriate.

Exercises (096):

1. How are TCTOs recorded on the AFTO Form 110 card?

2. If lines "B" and "C" of Part I have the number "6" entered, is an entry required in Block D of Part I? Why?

3. If Block 4 of Part II reads 09 over + 2, what is meant by this entry?

4. Is the following a correct entry for Part II, Block 1: "REV 1B-52G-6CF-1, 1 July 77"? Why?

5. In Part III, Block 4 has a "6" entered, Block 7 has a "2" entered and Block 8 has "10 Jan 78" entered. What entries must be made in Part I? Why?

6. Is the letter "C" a correct entry for Block 7 of Part IV? Why?

097. Define supplemental and annual checks, and specify the procedures for insuring the adequacy, completeness, and currency of TO files.

Checking Files. Contents of TO files are checked against AFTO Forms 110 and listings in the NI&RTs to insure that the files are maintained current. Checks required are supplement checks and annual checks.

Supplement checks. After AFTO Form 110 records and TO files are initially established, their currency and accuracy will be checked against each new NI&RT supplement. These checks consist of checking AFTO Forms 110 against new or revised listings of rescinded, reclassified, replaced, renumbered, cancelled, and deleted TOs. Shop supervisors will help in these checks, as they are required to review each new NI&RT supplement to determine if newly published TOs apply and are needed in their areas of responsibility.

The minus symbol (-) posted in Block D, Part I, below the file account number on the AFTO Form 110 will be used to indicate that the TO is in the file but some increment (basic, revision, change, or supplement) of the current issue is missing. Absence of complete sets is indicated by the difference between lines B and C. The activity will initiate and record on Part IV of AFTO Form 110 a requisition for the missing TO sets or increments.

The AFTO Forms 110, Part I, for the TOs that are listed in NI&RT as rescinded, renumbered, cancelled, or deleted will be marked to indicate this status by annotating above the TO number. The AFTO Form 110 for cancelled, deleted, and rescinded TOs should be tabbed or otherwise identified and checked against the next issue of the applicable basic NI&RT. If the TOs are not listed, the AFTO Forms 110 and the TOs may then be destroyed. The AFTO Form 110 for renumbered TOs should be appropriately established under the current number.

Annual checks. The contents of each active file, as they apply to one applicable NI&RT, will be checked annually against the current issue of the appropriate NI&RT (including current supplements if any) and the AFTO Form 110 file for the purpose of uncovering deficiencies or excesses in the file that may have been overlooked while making the supplement checks. Methods for conducting these checks are discussed in the following paragraphs.

An annual check includes checking the AFTO Form 110 records and all TOs in file against the basic NI&RT and the current cumulative supplement, if the supplement exists. Annual checks assure that TOs in the file are current and complete. Procedures described in the supplement checks apply here concerning retention and marking of incomplete and replaced TOs, requisition of missing TO sets and increments, and updating status records on the AFTO Forms 110. Since shipment of updated TO publications precedes distribution of affected indexes, it is a normal condition for later TO revisions, changes, and supplements to be in the TO file than are listed in the current NI&RT.

Annual checks need not be accomplished all at one time, but should be conveniently scheduled and accomplished throughout the year. (For example: The file may be checked against TO 0-1-01 and TO 0-1-02 NI&RTs and appropriate AFTO Form 110 cards in January; against TO 0-1-2, 0-1-3, and 0-1-4 NI&RTs and appropriate AFTO Form 110 cards in February; and so on, until each applicable NI&RT and all AFTO Forms 110 are checked. The established schedule should then be repeated for following years.

Supervisory inspections. Supervisory inspections are required on all workcards, checklists, and code manuals. They include 7-day checks and semiannual inspections.

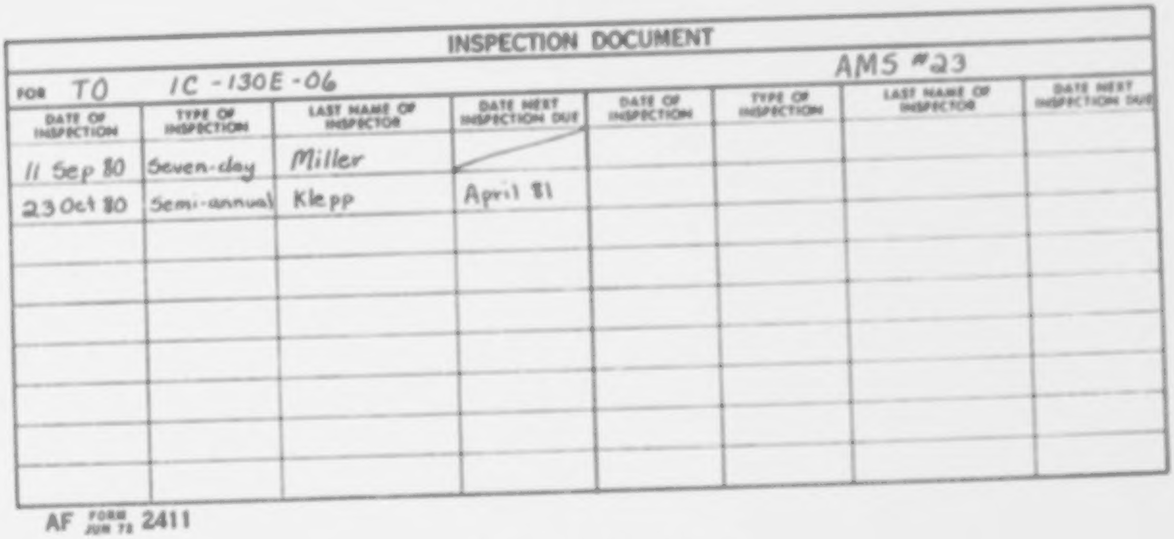
a. Seven-day checks. Quality Control monitors all changes, supplements, and revisions to workcards, checklists, and code manuals. They publish a weekly list of all changes, supplements, revisions, etc., that are received during the week. Shop supervisors are required to review this listing and insure that each publication on the list that applies to their area of responsibility is either properly filed or requisitioned. As the name of this check implies, it must be accomplished within 7 days of the date the list was published or within 7 days of the effective date or the date of receipt of the publication, whichever is the latest. This check must be documented on an AF Form 2411, Inspection Document, which is filed behind the title page of the publication (see fig. 4-11).

b. Semiannual inspections. All workcards, checklists, and code manuals must also be inspected semiannually for completeness and currency. This inspection must be accomplished by a supervisor, not necessarily the shop chief, prior to the last day of the month in which it is due.

If you file a change or supplement to one of these publications, or notice that the supervisory inspection has not been accomplished, notify your shop supervisor. This inspection, too, should be documented on the AF Form 2411.

Exercises (097):

1. Briefly define supplement checks.
2. Briefly define annual checks.
3. During a supplement check, you discover that TO 33D7-3-60-2 has change 15 missing; what should you do?
4. What should you do if you discover that TO 1B-52G-2-11 has been deleted?
5. If your TO has a later change date than what is listed in the current NI&RT, what action should you take and why?
6. Why should you inform your shop supervisor when new NI&RT supplements are received?
7. What publications require supervisory inspections?
8. Explain briefly the two types of supervisory inspections required on publications.



INSPECTION DOCUMENT

FOR TO IC -130E -06 AMS #23

DATE OF INSPECTION	TYPE OF INSPECTION	LAST NAME OF INSPECTOR	DATE NEXT INSPECTION DUE	DATE OF INSPECTION	TYPE OF INSPECTION	LAST NAME OF INSPECTOR	DATE NEXT INSPECTION DUE
11 Sep 80	Seven-day	Miller					
23 Oct 80	Semi-annual	Klepp	April 81				

AF FORM JUN 78 2411

Figure 4-11. AF Form 2411.

098. State procedures for filing TOs and keeping them up to date.

Filing Technical Orders. The importance of correct and current filing cannot be overemphasized. It is important to check replacement notes on the cover page to be sure that no page is destroyed which is not replaced by a new page or shown as deleted. File all TOs within a maximum of 5 workdays from date received, with the exception of the following:

a. Interim TOs (ITO) must be filed within 24 hours after receipt. Senior unit operations and maintenance officers may waive the 24-hour filing requirement for subaccounts, provided that the ITO will be filed in the affected TO prior to use.

b. Technical orders issued to individuals for operating or maintaining equipment must be filed prior to use.

c. When a change or revision to a TO containing technical order field change notices (TOFCNs) or interim TOFCNs (ITOFCNs) is received, an updated ITOFCN and/or TOFCN index sheet will be issued and must be filed concurrently. The above filing limit does not begin until the change or revision and the compatible ITOFCN and/or TOFCN index sheet is received.

d. When foldout pages are grouped at the back of a new basic TO, revision, or change by the printer, they will be filed by the file maintenance activity in sequence as indicated in the list of effective "A" pages.

e. Routine TO changes received out of sequence may be held until they can be filed sequentially.

Technical orders with effective dates. An effective date may appear on the title page of TOs. A TO effective date is normally used when data in the TO is used in conjunction with a computer program and procedures or data in the TO are to be implemented on the date the computer program or program change is implemented. The effective date will be on the title page above the authority note. The TO will normally be issued well in advance of the effective date. The effective date will be later than the basic date. Such TOs will be distributed immediately upon receipt; however, revisions will not replace the existing TO in the active file until the effective date. Likewise, changes will be held and will not be placed in the active file until the effective date. TOs received without an effective date are normally placed in the active file upon receipt. Work unit code manuals frequently have effective dates.

Interim technical orders. These TOs will be filed within the binders in proper sequence, depending on type (that is, supplements, ITOFCN, etc.). If necessary, they may be mounted on standard-size sheets and the required holes punched.

Revisions. These TOs are checked and filed in the following manner:

a. Before filing, check the replacement note, TO number, and title page against the title page of the TO being replaced.

b. If no discrepancy exists, remove the old TO and file the new replacement TO. When checked data are not in agreement, ascertain the reason for the discrepancy. If the reason cannot be ascertained, the appropriate TODCA must be notified by letter, message, or telephone. Filing is completed if at all possible and discrepancies annotated on the "A" page.

c. If the replacement note states that only part of another TO is replaced, that part is removed; if it cannot be removed, it is marked out and a notation made on the title page reflecting the TO number that replaced the marked portion.

Changes. Review and file changes to basic TOs in the following manner.

a. Before filing, check the complete change against the new listing on the list of effective "A" pages. Check the basic date on the cover page of the change against the basic date of the cover page to be replaced. Check the effective date.

b. File changes received with foldout pages assembled in the back of the change in page-number sequence as indicated on the list of effective "A" pages.

c. Place changes for which there are no basic TOs in the file in regular sequence in the file. Check records to insure that the basic TOs have been requisitioned and that initial distribution requirements have been properly established. Also, when it is determined by the check in item *a* above that a prior change is missing, file the change which is on hand, annotate the title page to show the missing change, and requisition in the missing change or complete basic TO, as appropriate.

d. When a page is listed on the list of effective "A" pages as a changed page, but the change or change number (whichever is applicable) has been omitted from the page itself, the change date or change number must be inserted on the page by the person maintaining the file.

e. When a changed page is received that is not listed as such on the list of effective "A" pages, the correct page listing should be inserted in the proper place by the person maintaining the file.

f. When a page is listed with a current change number on the list of effective "A" pages and no page of that number is contained in the change, annotate "pages not received with change" on the list of effective "A" pages, as well as on the affected page.

g. When a changed page is received with a publication date that supersedes the date reflected on the list of effective "A" pages, the old date will be lined out on the "A" page, and the latest change date will be inserted by the person maintaining the file.

h. If the basic date on a changed title page does not agree with the basic in the file, check the NI&RT to determine the correct basic date and take appropriate action to obtain the correct TO or to correct the discrepancy. Filing of changes will be completed if at all possible, regardless of discrepancies on the title and "A" page. Discrepancies are annotated on the title and/or "A" page of the TO and are reported to the appropriate TO distribution control activity (TODCA) by letter, message, or telephone.

Supplements. Supplements are integral parts of the basic TOs and are filed in the following manner.

a. Safety and operational supplements will be filed in reverse numerical sequence in front of the basic manual regardless of the type of manual. When a single block of numbers has been used to number both types of supplements, they must not be separated by type; otherwise, the safety supplements will be filed in front of the operational supplements. The supplement status page should remain with the supplement.

b. Department of the Army and Navy changes and Air Force supplements to bound manuals are filed in alphanumeric order immediately following the basic publication. A reference to the change or supplements will be made on the cover page of the technical order.

c. Routine and/or other supplements to TOs and NI&RTs are filed in alphanumeric sequence following the basic TO and a reference to the supplement is made on the cover page of the basic technical order.

d. When supplements are assigned a security classification other than the classification assigned to the basic technical order, each may be filed separately according to its classification.

e. When a supplement to a TCTO is filed, a reference to the supplement is entered on the first page of the basic TCTO. Marking entries opposite each paragraph in the basic TCTO affected by the supplement is the option of the using command regardless of title page notes.

f. Reference to the supplement in safety operational supplements is entered on the cover page of the basic TO. Such reference is not necessary for aircraft flight manuals, because flight manuals and supplements contain a status page that lists all outstanding supplements as of the publication date. Marking entries opposite each paragraph affected by the supplement is the option of the using command, regardless of title-page notes. Safety and operational supplements are maintained in all files where the basic TOs are required.

Technical order page supplements (TOPS). The TOPS pages filing instructions are outlined below.

a. The TOPS title pages are filed in front of the existing TO title page. The existing TO title page and its list of effective pages are retained and not removed. Only the latest TOPS page is issued and the list of effective pages is cumulative and includes all active TOPS pages.

b. The TOPS data pages are filed opposite and facing the affected TO pages.

c. The requirement for annotation of the paragraph(s) or sentence(s) in the basic TO affected by the TOPS is optional.

d. The TOPS pages are not removed from active TO files unless one of the following conditions exists.

(1) Notification of the TOPS replacement is contained on the title page of a standard change and/or revision or cumulative TO page supplement.

(2) The TOPS sequential number is deleted from one numerical index and requirements table.

Appendixes. Appendixes are continuations of basic TOs and are filed following the basic TO or the preceding appendix.

Department of the Army publications. Department of the Army publications applicable to the Air Force may be placed together in numerical order outside the standard Air Force binder file. A cross-reference sheet for each such publication, filed separately, is inserted in numerical order within the binders, and contains the Air Force assigned TO number, title of the TO, reference to the file location of the TO, and any other pertinent information considered necessary. Army publications may be drilled for standard binder filing and placed in numerical order with the standard Air Force technical orders.

Pack-up publications. One copy of each publication (interim, preliminary, or commercial) packed with equipment is placed in the appropriate file upon receipt, after review for currency and completeness, if not already in the file. This will insure immediate availability. Additional or extra copies may be placed in the extra copies file, used as work copies, or disposed of, in accordance with TO 00-5-2. Initial distribution must be established to keep these TOs current.

Inspection workcards, sequence charts, code manuals, TO checklists, pocket-size TOs, explosive ordnance disposal (EOD), and 33K series TOs. Each file activity is authorized to devise its own method for filing these technical orders.

Commercial publications. Commercial publications, authorized for USAF use and having a TO number assigned, may be drilled for standard binder filing and placed in numerical order in binders along with other technical orders. Any identifying title page sheets must be filed preceding the commercial publication so identified. Commercial publications may also be filed separately from other TOs. When this method is used, the commercial publications are maintained in numerical order and any identifying title page sheets filed with the standard TOs in numerical order, properly annotated by file personnel to reference the file location of the commercial publications.

Preliminary technical orders (PTO). Filing requirements are outlined below.

a. Preliminary TOs are not filed with formal TOs, but are maintained in separate files that are clearly identified.

b. Personnel maintaining PTO files are responsible for insuring that the sequential copy number (except flight manuals) on each change or supplement PTO agrees with the sequential copy number assigned to the basic preliminary technical order.

c. Upon receipt of a new cover page for a PTO identifying the availability of a formal TO, the formal TO may be requisitioned.

Technical order field change notices (TOFCNs) and interim TOFCNs (ITOFCNs). The ITOFCN or TOFCN index sheet is filed facing the "A" page; ITOFCNs and TOFCNs are interfiled within the TO with each page of the TO. The ITOFCN or TOFCN is removed from the TO upon receipt of a replacement technical order change notice (TOCN) or rescission notice from the central technical order control unit.

Technical order change notices (TOCNs). A TOCN issued against a TO is interfiled into the affected TO in the same manner as a change. The TOCN cover page is filed preceding the title page, or it may be destroyed after the formal change has been filed in the affected TO.

Renumbered technical orders. When a TO has been renumbered, line out the old number on the cover page, insert the new number, and file the TO in correct sequence. Use of pen and ink is authorized to annotate renumbering action.

Maintenance of indexes. Maintenance of indexes must be in accordance with instructions contained in the preface of TO 0-1-01, Numerical Index and Requirement Table, and other applicable instructions in this section.

Exercises (098):

1. Excluding the few exceptions, how soon must a TO be filed after receipt?
2. How does this filing limit apply to ITOs?
3. How are foldouts filed when they are grouped at the back of a TO change?
4. How are TO changes with effective dates filed?
5. How would you file a TO revision when the "A" page contains discrepancies?
6. How are TO changes checked for accuracy before filing?
7. How are changes filed for which there is no basic TO on hand?
8. If the changed page and the "A" page do not agree, how would you file this change?
9. How are safety and operational supplements filed?
10. How are routine supplements to TOs and NI&RTs filed?
11. How are TOPS data pages filed?
12. When Army publications are not included in Air Force TO files, how are they filed?
13. How are pocket-size TOs filed?
14. How are PTOs filed?

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Bibliography

ECI Courses

CDC 325X0, Volume 1, *Automatic Flight Control Systems Specialist.* Extension Course Institute, Gunter Air Force Station, Alabama 36118.

CDC 34155, Volume 1, *Analog Navigation/Tactics Training Devices Specialist.* Extension Course Institute, Gunter Air Force Station, Alabama 36118.

CDC 42354, Volume 1, *Aircraft Pneudraulics Systems Mechanic.* Extension Course Institute, Gunter Air Force Station, Alabama 36118.

Department of the Air Force Publications

AFR 0-2, *Numerical Index of Standard and Recurring Air Force Publications.*

AFR 5-1, *Air Force Publications Management Program.*

AFR 35-10, *Dress and Personal Appearance of Air Force Personnel.*

AFR 39-1, *Airman Classification Regulation.*

AFR 39-6, *The Enlisted Force Organization.*

AFR 39-7, *Airman Career Information.*

AFR 39-29, *Promotion of Airmen.*

AFR 50-23, *On-the-Job Training.*

AFR 55-30, Volume 1, *Operations Security.*

AFR 66-33, *Preventing Foreign Object Damage (FOD) to Aircraft, Missiles, or Drones.*

AFM 66-278, *Maintenance Management Information and Control Systems (MMICS).*

AFR 127-2, *The USAF Mishap Prevention Program.*

AFR 127-12, *Air Force Occupational Safety and Health Program.*

AFR 127-101, *Ground Accident Prevention Handbook.*

AFR 161-35, *Hazardous Noise Exposure.*

AFM 171-114, *Base Level Inquiry System (BLIS).*

AFM 171-177, Volume 2, *Air Force Online Data System, Users Manual.*

AFR 207-1, *The Air Force Physical Security Program.*

DOD 5200.1-R/AFR 205-1, *Information Security Program.*

AFOSH Standard 127-1, *Walking Surfaces.*

AFOSH Standard 127-9, *Manually Propelled and Self-Propelled Mobile Work Platforms and Scaffolds (Towers).*

AFOSH Standard 127-31, *Personal Protective Clothing and Equipment.*

TO 0-1-01, *Numerical Index, Alphabetical Index, and Cross-Reference Table Technical Orders.*

TO 0-1-02, *Index to General Publications.*

TO 0-2-1, *Alphabetical Equipment List Cross-Reference with Technical Order Number Groups.*

TO 0-4-2, *Cross-Reference Table of Time Compliance Technical Order Numbers to Applicable Data Code Numbers.*

TO 0-4-6-1, *Numerical Cross-Reference Index—Equipment Numbers to Technical Order Numbers.*

TO 00-5-1, *Air Force Technical Order System.*

TO 00-5-2, *Distribution and Storage of AF Technical Order System Publications.*

NOTE: None of the items listed in the bibliography are available through ECI. If you cannot borrow them from local sources, such as your base library or local library, you may request one item at a time on a loan basis from the AU Library, Maxwell AFB AL 36112, ATTN: ECI Bibliographic Assistant. However, the AU Library generally lends only *books* and a limited number of *AFMs*. TOs, classified publications, and other types of publications are not available. Refer to current indexes for the latest revisions of and changes to the official publications listed in the bibliography.

Answers for Exercises

CHAPTER 1

Reference:	
001 - 1.	Avionics Systems Career Field.
001 - 2.	Automatic flight control/instrument subdivision.
001 - 3.	Skill level.
001 - 4.	Air Force Specialty (1—Avionics Instruments).
001 - 5.	Basic airman and 99000 respectively.
001 - 6.	Completion of the basic instrument technical training course at Chanute AFB.
001 - 7.	AFSC 32551.
001 - 8.	The 9 skill level.
001 - 9.	Avionics instrument systems technician.
001 - 10.	By on-the-job training.
001 - 11.	By attending a technical training school.
001 - 12.	After obtaining a 5 skill level.
002 - 1.	To increase your skill level by improving job knowledge.
002 - 2.	Job knowledge and job proficiency.
002 - 3.	In the specialty description.
002 - 4.	Awarded, primary, duty, and control. Awarded AFSC identifies the highest AFSC a person has earned and been awarded. Primary AFSC is the highest AFSC a person is qualified to perform in. Duty AFSC identifies the level of duty a person is assigned to perform. Control AFSC controls assignments and training eligibility.
002 - 5.	b, c, e, f.
002 - 6.	Control.
002 - 7.	Awarded and primary.
002 - 8.	Duty AFSC.
003 - 1.	Commanders.
003 - 2.	When airmen are eligible and qualified.
003 - 3.	By doing your job to the best of your ability, thereby getting very high marks on your APRs; constantly studying the general military subjects; and being knowledgeable of current happenings throughout the world.
003 - 4.	Specialty Knowledge Test, Promotion Fitness Exam, time in grade, time in service, Airman Performance Reports, and decorations.
003 - 5.	Air Force specialty knowledge.
003 - 6.	Promotion Fitness Examination.
003 - 7.	By awarding 1/6 point for each month of active Federal military service.
003 - 8.	SKT and PFE scores.
003 - 9.	APR.

See Module 10009 for answers to objectives 004-046.

CHAPTER 2

047 - 1.	To safeguard classified material peculiar to that command.
047 - 2.	DOD 5200.1-R/AFR 205-1.
047 - 3.	Major commands and their assigned units.
047 - 4.	The importance of classified material.
047 - 5.	Policies for safeguarding classified information and explanations on how to identify, classify, and protect classified material.
048 - 1.	According to its degree of importance.
048 - 2.	Top Secret, Secret, and Confidential.
048 - 3.	Top Secret is defined as "having such status that its unauthorized disclosure would cause exceptionally grave damage to the United States."
048 - 4.	Secret.
048 - 5.	Damage to the national security.
049 - 1.	No. A person with a Secret clearance does NOT have access to all Secret information, but *only* to that required to do the job.
049 - 2.	The person possessing a classified document.
049 - 3.	No. The file clerk has no need to know.
049 - 4.	The airman.
049 - 5.	Avoid classified subjects if possible; otherwise, establish the other person's authorization and need to know. Insure that unauthorized persons cannot overhear classified information.
049 - 6.	YOU.
049 - 7.	Only those individuals whose official duties require the possession of classified material and who have a valid need to know.
050 - 1.	(1) d. (2) a. (3) b. (4) e. (5) d.
051 - 1.	(1) d. (2) e. (3) b. (4) c. (5) f. (6) h.
052 - 1.	(1) d. (2) b. (3) c. (4) f. (5) g. (6) a. (7) e.
052 - 2.	Because the Air Force has nuclear weapons and can strike quickly at any attacker.
052 - 3.	Refuse the request and immediately report the request to your supervisor, commander, or OSI.
052 - 4.	Practice security consciousness at all times, and report all suspicious acts, requests, and contacts immediately.
052 - 5.	Helping Hand and Covered Wagon.
053 - 1.	The exchange badge procedure.
053 - 2.	The signature and credentials check.
053 - 3.	The personal recognition procedure.

053 - 4 The telephone or radio verification.

053 - 5. To deny unauthorized persons access to critical operational resources.

054 - 1. To identify persons who have been granted unescorted entry authority.

054 - 2. To identify specific numbered areas on the base to which unescorted entry is permitted.

054 - 3. The holder of the badge can escort other people into that particular area.

054 - 4. A recurring need to enter the area and the proper security clearance.

054 - 5. Those individuals who hold responsible supervisory positions.

054 - 6. Determining if the individual should be permitted to enter the area.

054 - 7. Yes, but only after the escort official has taken the individual into the restricted area.

055 - 1. To reduce the capability of an enemy to gather useful intelligence data about our operations and activities.

055 - 2. Information about our limitations, objectives, operation times and locations, forces involved, methods of employment, results of operations or exercises, sources of information, methods of data collection, etc.

055 - 3. To all personnel and agencies connected with or having knowledge of any operation, event, project, or program.

055 - 4.
- a. This question could very well be sensitive. It could indicate a deployment to Korea.
- b. This statement could also be sensitive. Combined with other bits of information overheard in the same way, it could give insight to classified information about those special missions.
- c. This, too, could be sensitive. It depends upon the circumstances. It could give insight to the results of an operation or identify limitations of assigned aircraft.
- d. This statement is probably sensitive. It could tell of actual wartime missions, help identify targets X and Y, or give insight into the type of training being conducted.
- e. This, too, could be sensitive. A statement like this could alert an enemy agent to find out more about possibly classified special missions, special training efforts, or imply the use of a fighter aircraft with a limited range.

056 - 1.
- (1) d. *Air Force Occupational Safety and Health Program.*
- (2) e. *Ground Accident Prevention Handbook.*
- (3) a. *Hazardous Noise Exposure.*
- (4) b. *Manually Propelled and Self-Propelled Mobile Work Platform and Scaffolds.*
- (5) f. *General Shop Practice Requirements for the Repair, Maintenance, and Test of Electronic Equipment.*
- (6) c. Occupational Safety and Health Act.
- (7) k. *Preventing Foreign Object Damage (FOD) to Aircraft, Missiles or Drones.*
- (8) g. *General Sanitation.*
- (9) l. *Personal Protective Clothing and Equipment.*

056 - 2. AFOSH Standard 127-1, *Walking Surfaces.*

056 - 3. AFR 127-12.

057 - 1. False. Your supervisor is responsible for your enrollment in the Hearing Conservation Program.

057 - 2. False. The supervisor is responsible for scheduling individuals for occupational physicals.

057 - 3. False. The supervisor must maintain a file of safety directives and related guidance.

057 - 4. True.

057 - 5. False. Enforcing safety directives is a supervisory responsibility.

057 - 6. False. Administering the FOD program is a supervisory responsibility.

057 - 7. True.

057 - 8. False. The greatest responsibility for your personal safety belongs to you.

058 - 1. Natural phenomena.

058 - 2. Unsafe acts and unsafe conditions.

058 - 3. Inattentiveness, excitability, impatience, and stubbornness.

058 - 4. Safety training.

058 - 5. The supervisor's orientation of a new arrival is used to determine whether or not additional or special safety training is required; therefore, it is a key step in safety training.

058 - 6. Safety briefings are short talks directed primarily toward job-related high-hazard areas, such as fuel tanks, around intake exhaust, and high-pressure hydraulic lines. They should be conducted weekly.

058 - 7. Eliminating the cause of the hazard by removing foreign objects from the vicinity of operating jet engines.

058 - 8. Identification, isolation, and control of the cause.

059 - 1. Fire is a chemical reaction between a combustible material and oxygen.

059 - 2. Four.

059 - 3. Class A fires involve wood, paper, or rags. Class B fires occur in flammable liquids such as fuels, oils, solvents, or greases. Class C fires occur in electrical equipment and are usually fueled by insulating materials or plastic compounds. Class D fires are fueled by combustible metals, such as magnesium, potassium, powdered aluminum, zinc, or sodium.

060 - 1.
- (1) c.
- (2) a.
- (3) b.
- (4) b.
- (5) a.
- (6) a.
- (7) b.
- (8) d.

060 - 2.
- a. False. A fire is starved when the fuel source has been removed. It is smothered when the oxygen has been removed.
- b. False. A water pump fire extinguisher is generally used to cool a fire.
- c. True.
- d. True.

060 - 3.
- a. Carbon dioxide is extremely cold. Caution must be exercised in the use of CO_2 to prevent frostbite.
- b. Once a foam extinguisher is inverted, the foam will flow until the extinguisher is empty. It must be refilled before it can be used again.
- c. Water conducts electricity and must not be used on electrical fires. Water will also make a petroleum fire spread instead of putting the fire out.

061 - 1. Damage to vital organs may be caused by absorption of the toxic agent (solvent or lubricant) into the bloodstream through prolonged breathing of vapors or by direct skin contact.

061 - 2. Through prolonged breathing of vapors and direct skin contact.

061 - 3. Store solvents and lubricants only in approved metal containers, and store them in areas outside of buildings where they will not be subjected to excessive heat, sparks, or flame.

061 - 4. Some solvents, while not actually flammable or volatile, will build up extreme pressure inside a sealed container when subjected to heat. This may cause the container to rupture, spraying or splashing the contents on personnel or equipment.

061 - 5. Flammable solvents (and lubricants) leaking from a container or otherwise exposed to sparks or open flame may readily ignite.
061 - 6. Many lubricants are not suitable for use in electrical equipment because they conduct electricity and cause equipment or system failures because of short circuits.
061 - 7. The solvent must be nonvolatile, nonflammable, and as nontoxic as possible.
061 - 8. (1) Putting them in the trash, (2) washing them down the drain, or (3) pouring them on the ground.

062 - 1. *Poor judgment.*
062 - 2. (1) Short circuits, (2) overloading, (3) accidental grounding, (4) poor electrical connections, and (5) misuse of equipment.
062 - 3. Turn the equipment off.
062 - 4. Do not wear any metal objects such as watches, rings, necklaces, metal rimmed glasses, etc., when working near any electrical potential.
062 - 5. Wooden-handled screwdrivers should not be used for electrical work since the wood can absorb moisture.
062 - 6. Know the location of main power switches in case power has to be turned off in an emergency. Never close a switch unless you know what is connected to the applicable circuit.
062 - 7. A voltmeter should NOT be handled or held when making a voltage measurement.
062 - 8. The safety observer for high-voltage maintenance should know how to turn the equipment off and should be capable of applying emergency first aid, including cardiopulmonary resuscitation (CPR).

063 - 1. The dangers of (1) blowing foreign objects such as filings, chips, and dirt into the eyes; (2) projectiles dislodged with enough force to injure personnel; (3) getting air into cuts; and (4) the pressure causing the hose to whip around uncontrolled.
063 - 2. Compressed air should not be used to remove dust or dirt from clothing because air blown into a small cut or opening in the body can inflate parts of that part of the body like a balloon. Approximately 4 pounds per square inch has been known to rupture the intestines.

064 - 1. The weight and size of the equipment. Do you need another person's assistance, or must you use a handtruck or forklift?
064 - 2. A squatting position, with your back straight, and allow your legs to exert the primary lifting force.

065 - 1 The work center supervisor.
065 - 2 Good arrangement or layout of work areas can best be achieved in the planning stages, but your interest and suggestions after the fact can help insure a safe work environment.
065 - 3. Scraps and wastes should be stored temporarily in suitable, self-closing metal containers until they can be disposed of properly.
065 - 4. Post warning signs or otherwise warn others so that they will be aware of the hazard.
065 - 5. They may protrude and present a tripping hazard. More important though is that it creates a potential fire hazard which may eliminate a path for escape.
065 - 6. In closed metal containers in a shelter detached and away from the building

066 - 1 (1) Tubes stored in bench stocks; (2) parts in the shop for bench check or installed on the aircraft; (3) test equipment stored in the shop.
066 - 2 A yellow background with black lettering and a magenta (a deep purplish red) symbol.
066 - 3. Although most of these tubes do not present a hazard of high radiation levels, a potential hazard does exist since the tubes could be broken and radioactive material could enter the body by way of cuts, ingestion, or inhalation.
066 - 4. (1) High frequency radio transmitters, (2) radar, or (3) electronic countermeasure devices.
066 - 5. Internal burns because of excessive heat buildup and eye cataracts.
066 - 6. Posting warning signs and avoiding entrance to the area of radiation.

067 - 1. The explosive charges which eject the canopy and seats.
067 - 2. Insure that the seat and canopy ejection safety pins are installed, and exercise particular care to avoid accidental priming or firing of the explosive charges. Avoid pulling a handle or flipping a switch *if you do not* know what the results will be.
067 - 3. A tool left in the cockpit could jam a control, short out an electrical circuit, or fly out and strike the pilot when he maneuvers the aircraft.
067 - 4. If you carelessly operate power-activated systems, you could damage equipment or seriously injure someone. If you are working on a power-activated system, deplete the hydraulic pressure, lock any moveable surfaces if possible, and put warning signs (danger tags) on the controls.

068 - 1. FOD is the abbreviation for foreign object damage. It is the term used to describe any foreign object that doesn't belong where it is, such as nuts, bolts, washers, tools, rocks, safety wire, etc., found loose on the flight line.
068 -2. Account for all tools, hardware, and components after each job. We can also clean our work areas and pick up and properly dispose of any foreign objects we find on the flight line.

069 - 1. (1) The intake, (2) the exhaust, (3) the turbine plane, (4) the cartridge starter, (5) the auxiliary air inlet doors, (6) the heat generated by the engine, and (7) the noise generated by the engine.
069 - 2. Normally, 25 feet.
069 - 3. Because of the temperature and force of the exhaust.
069 - 4. You should always work forward or aft of the turbine wheel plane of rotation when the engine is running.
069 - 5. By a painted RED line on the engine cowling.
069 - 6. (1) The turbine wheel plane of rotation and (2) the toxic fumes given off when the charge is exploded.
069 - 7. Because they operate automatically.
069 - 8. (1) It can interfere with speech communications, (2) cause mental and physical fatigue, and (3) eventually seriously damage your hearing.
069 -9. Hearing, once lost, cannot be restored, but when such a loss is identified, proper protection will prevent further loss.

070 - 1. A base assembly, upper structure assembly, platform assembly, and on the larger stands, a hydraulic system for raising and lowering the platform.
070 - 2. (1) B-1 stand, (2) B-2 stand, (3) B-4 stand, (4) B-5 stand, and (5) C-1 stand.
070 - 3. By inserting the U-shaped steel device into the grooves in the cylinder assembly.
070 - 4. The C-1 maintenance stand is a fixed height and is nonadjustable.
070 - 5. To provide working platforms at variable heights.
070 - 6. Use caution when you raise or lower a scissors-type maintenance stand (B-4 or B-5); never stand on the ladder.

CHAPTER 4

071 - 1. Standard publications are used to announce policies, assign responsibilities, prescribe procedures, direct actions, and inform or motivate personnel, whereas specialized publications provide information of a highly specialized nature.
071 - 2. Air Force pamphlets (AFPs).

071 - 3. Operating instructions.
071 - 4. Supplements.
071 - 5. Behind the basic publication or behind the supplement of the next higher headquarters.

072 - 1. AFR 5-1.
072 - 2. They are used to simplify their reference and control. The first number shows the basic subject and the second number shows the specific area of the basic subject covered.
072 - 3. The zero dash 2 (0-2).
072 - 4. Section *IV*.

073 - 1. Write in the current date of your manual, 3 May 75.
073 - 2. The publication is not available but is needed and is on order.
073 - 3 On or before 6 May.

074 - 1. Wing or base level—usually no lower.
074 -2. Functional publication library.
074 - 3. That shop is responsible for revising, changing, or rescinding that regulation.

075 - 1. The first part of a three-part TO number identifies the TO category. The second part identifies aircraft model, series, and configuration. The third part identifies the kind of TO.
075 - 2. They indicate that the TO is a maintenance support publication which provides troubleshooting procedures.
075 - 3. It may identify a section of a sectionalized TO or the kind of TO.
075 - 4. To further break down an equipment group that is too complex for the four-part number to handle.
075 - 5.
- a. First part, 1C-, identifies a cargo aircraft TO.
- b. First part, 0-, identifies an index.
- c. First part, 00-, identifies procedural TOs.
- d. Third part, -4, identifies the kind of TO, specifically, an illustrated parts breakdown.
- e. Third part, -6, identifies the kind of TO, specifically, inspection requirements.

076 - 1 (1) Technical manuals, (2) methods and procedures TOs, (3) index type TOs, (4) time compliance TOs, and (5) abbreviated TOs.
076 - 2. TOs that provide information on the installation, operation, maintenance, and handling of Air Force equipment and material.
076 - 3 Dash one (-1) flight manual.
076 - 4. A 2, if the TO contained maintenance instructions. The complete TO number would be 1F-5B-2-9.
076 - 5.
- a. 1B-52H-1 is a flight manual.
- b. 1C-130E-2- is an organizational maintenance manual.
- c. 1C-141B-4 is an illustrated parts breakdown.
- d. 1F-4C-6 is an inspection requirements manual.
- e. 1T-43-101 is a general aircraft TO.
- f. 1C-135(K)A-2-11MS-3 is a maintenance support manual in the job guide category.

077 - 1. By providing information and instructions in supervisory and administrative areas.
077 - 2. The general publications, double zero (00) category.

078 - 1. The primary difference is that immediate action TCTOs are issued to correct *existing* unsafe conditions, and urgent action TCTOs are issued to correct *potentially* unsafe conditions.
078 - 2 Immediate action TCTOs are bordered with red Xs, urgent action TCTOs are bordered with alternating circled red Xs and red diagonals; and routine action TCTOs do not have distinguishing red symbols.

079 - 1. (1) Alphabetical, (2) numerical, (3) cross-reference, and (4) list of applicable publications (LOAP).
079 - 2. Use the alphabetical index, TO 0-2-1, and look up generators.
079 - 3. Look up TTU-205C/E in the numerical cross-reference index of equipment numbers to TO numbers which is TO 0-4-6-1. You could also look it up in TO 1F-15A-01, the list of applicable publications for the F-15 aircraft. Another method is to look up generators in the numerical index, TO 0-1-01, and then read through the designated NI&RT to find the correct pressure temperature test set.
079 - 4. TO 0-1-5-3.

080 - 1.
- a. The purpose of inspection workcards is to give the inspection requirements listed in the -6 technical manual in such a manner that each person accomplishing the inspection has all applicable inspection requirements immediately available.
- b. The purpose of inspection sequence charts is to guide and control work assignments during periodic inspections.
- c. The purpose of checklists is to list the different steps of a task or job in chronological order, so that no step is omitted and proper system operation is achieved.
- d. The purpose of inspection worksheets is to identify the inspection requirements listed in the -6 technical manual and provide spaces to establish credit and identify responsibility for each item of the inspection.

081 - 1. By a heavy black line in the outer margin beside the changed part.
081 - 2. When there isn't time to include the information in a change or revision to the basic TO.
081 - 3. Only when parts of the existing TO are affected.
081 - 4. On the "A" page of a TO.
081 - 5. Complete new editions of a TO.

082 - 1. To test and verify procedures developed for use with the first or early production models of Air Force equipment.
082 - 2. In a separate file, which must be clearly marked.

083 - 1. Practice using TOs and the TO system in order to become proficient in their use.
083 - 2. Use the table of contents to determine the precise section, page, or paragraph containing the needed information.
083 - 3. The OJT supervisor.

084 - 1. (1) WARNING, (2) CAUTION, and (3) NOTE.
084 - 2. It could result in serious injury or death.

085 - 1. Yes, a deficiency report should be submitted. Steps 15 and 16 are reversed and equipment is subject to damage as the TO is now written.
085 - 2. Air Force Logistics Command (AFLC).
085 - 3. Check with your supervisor first, then contact Quality Control for assistance.

086 - 1. Section I of the IPB explains the use of codes, designators, etc., used in the other major sections of the IPB. Section I also lists related technical orders, vendors' names and addresses, and engineering change proposals. It normally includes illustrations and corresponding instructions which show how to use the IPB.
086 - 2. Determine the function and application of the part. Turn to the table of contents and select the most appropriate title. Then turn to the referenced illustration and find the part.
086 - 3. Refer to Section III, Numerical Index. Locate the part number and note the figure and index number assigned to the part number.

087 - 1. Section II.
087 - 2. Section II.

087 - 3. (1) Figure and Index Number, (2) Part Number, (3) Description, (4) Units per Assembly, and (5) Usable on Code.
087 - 4. It indicates limited usage of a part.
087 - 5. The relationship of the part to the complete assembly.
087 - 6. That the next higher assembly of which this one is a part is shown in figure 21.
087 - 7. The number of these parts used on the next higher assembly.

088 - 1. It lists all part numbers appearing in the Group Assembly Parts in alphanumerical sequence.

089 - 1. It provides a rapid means of cross-referencing between TO schematic wiring diagrams and the figure and index numbers in Section II of the IPB.

090 - 1. In conjunction with troubleshooting diagrams or charts.
090 - 2. To identify the specific wire and isolate the problem to a specific segment of the wire.
090 - 3. To permit easy cross-reference to wiring diagram drawings and IPB illustrations.
090 - 4. In order to understand the abbreviations, symbols, and switch or relay contact positions.

091 - 1. The 3 in the wire number 3E124C20 indicates that you are troubleshooting a system on the number 3 engine.
091 - 2. As part of a flight instrument system.
091 - 3. It means that the system uses three-phase power and that particular wire carries "A" phase power.
091 - 4. The 20 in wire number 4E018C20 indicates that 20-gauge wire is the proper size of wire to use to replace a damaged segment.
091 - 5. The letter "A" in wire number L266A20 identifies the first segment of the circuit starting at the power source; therefore, the third segment would have wire number L266C20.

092 - 1. The Designation Cross Reference section in a wiring diagram manual provides a complete listing of every circuit and is used to find information in the wiring diagrams and locations on the aircraft.

093 - 1. They are used to illustrate the location of components and areas on the aircraft.
093 - 2. Station number references and illustrated parts breakdowns.

094 - 1. Wiring diagrams show complete wiring connections from component to component.
094 - 2. Wiring diagrams are normally the only source for identifying wire numbers.

095 - 1. NI&RTs show the status of TOs and provide a basis for determining distribution and requisition requirements and updating TO files and records.
095 - 2. These TOs are listed in Part II of the NI&RT.
095 - 3. Below the TO number. If no requirements indicator is listed, the TO cannot be ordered.
095 - 4. It is shown as the first element in the title column.

096 - 1. TCTOs may be recorded on the AFTO Form 110 for the TO series listing. As a major command option, a separate AFTO Form 110 may be maintained for each TCTO required. Those TCTOs not required will be listed on Part III of the TCTO series card with an NR in Block 5.
096 - 2. No entry is required in Block D, because the 6 on line B indicates that 6 are required and the 6 on line C indicates that 6 are on hand.
096 - 3. It means that account 09 wants its level increased by 2.
096 - 4. No. The TO number is not required. Only the letters "REV" for revision and the date of the revision need to be entered.
096 - 5. Block C of Part I must be changed from 6 to 8 because the total quantity required is now on hand. The minus (−) in Block D must be erased because the shortage no longer exists.
096 - 6. Yes, the letter "C" is used in Block 7 of Part IV to show that the requisition was cancelled.

097 - 1. Supplement checks consist of checking AFTO Forms 110 against new or revised listings and listings of rescinded, reclassified, replaced, renumbered, cancelled, and deleted TOs within 10 working days following receipt of supplement NI&RT.
097 - 2. Checking AFTO Form 110 records and all TOs in file against basic NI&RT and current cumulative supplement(s).
097 - 3. Order change, annotate AFTO Form 110, and mark TO "incomplete."
097 - 4. Annotate the AFTO Form 110 "deleted" and flag it with a tab. If the next issue of the applicable basic NI&RT does not list the TO, destroy the AFTO Form 110 and the TO.
097 - 5. None, because this is a normal condition.
097 - 6. Your shop supervisor should review all NI&RTs and supplements to determine if newly published TOs are required for the shop.
097 - 7. Workcards, checklists, and code manuals.
097 - 8. Seven-day checks are required on workcards, checklists, and code manuals to insure that they are on hand and properly filed. Semiannual checks are required to insure that work cards, checklists, and code manuals are complete and current.
098 - 1. Within 5 working days from the date received.
098 - 2. ITOs must be filed within 24 hours unless waived by the senior unit operations or maintenance officer.
098 - 3. In sequence as indicated in the list of effective pages.
098 - 4. They are filed on their effective date.
098 - 5. If the reasons for the discrepancies cannot be ascertained, the appropriate TODCA must be notified. If the reasons can be ascertained, then annotate the discrepancies on the "A" page.
098 - 6. The complete change will be checked against the new listing on the list of effective "A" pages. The basic date on the changed and replaced covered pages must agree.
098 - 7. Changes are placed in regular sequence in the file.
098 - 8. File the change and correct the changed page, or "A" page, as appropriate.
098 - 9. In reverse numerical sequence in front of the basic manual, regardless of the type of manual.
098 - 10. In alphanumeric sequence behind the basic TO, and a reference to the supplement is made on the title page of the TO.
098 - 11. TOPS data pages are filed facing the affected pages.
098 - 12. In numerical sequence outside the standard file, and a cross-reference sheet for each such publication filed separately will be inserted in numerical order within the standard Air Force binder.
098 - 13. You can devise your own method for filing pocket-sized TOs.
098 - 14. In separate files which are clearly identified.

S T O P - 1. MATCH ANSWER SHEET TO THIS EXERCISE NUMBER.
2. USE NUMBER 2 PENCIL ONLY.

EXTENSION COURSE INSTITUTE
VOLUME REVIEW EXERCISE

32551 01 23
CAREER FIELD FAMILIARIZATION

Carefully read the following:

DO's:

1. Check the "course," "volume," and "form" numbers from the answer sheet address tab against the "VRE answer sheet identification number" in the righthand column of the shipping list. If numbers do not match, return the answer sheet and the shipping list to ECI immediately with a note of explanation.
2. Note that item numbers on answer sheet are sequential in each column.
3. Use a medium sharp #2 black lead pencil for marking answer sheet .
4. Write the correct answer in the margin at the left of the item. (When you review for the course examination, you can cover your answers with a strip of paper and then check your review answers against your original choices.) After you are sure of your answers, transfer them to the answer sheet. If you have to change an answer on the answer sheet, be sure that the erasure is complete. Use a clean eraser. But try to avoid any erasure on the answer sheet if at all possible.
5. Take action to return entire answer sheet to ECI.
6. Keep Volume Review Exercise booklet for review and reference.
7. If mandatorily enrolled student, process questions or comments through your unit trainer or OJT supervisor. If voluntarily enrolled student, send questions or comments to ECI on ECI Form 17.

DON'Ts:

1. Don't use answer sheets other than one furnished specifically for each review exercise.
2. Don't mark on the answer sheet except to fill in marking blocks. Double marks or excessive markings which overflow marking blocks will register as errors.
3. Don't fold, spindle, staple, tape, or mutilate the answer sheet.
4. Don't use ink or any marking other than a #2 black lead pencil.

NOTE: **NUMBERED LEARNING OBJECTIVE REFERENCES ARE USED ON THE VOLUME REVIEW EXERCISE.** In parenthesis after each item number on the VRE is the Learning Objective Number where the answer to that item can be located. When answering the items on the VRE, refer to the Learning Objectives indicated by these Numbers. The VRE results will be sent to you on a postcard which will list the actual VRE items you missed. Go to the VRE booklet and locate the Learning Objective Numbers for the items missed. Go to the text and carefully review the areas covered by these references. Review the entire VRE again before you take the closed-book Course Examination.

MULTIPLE CHOICE

Note to Student: Consider all choices carefully and select the best answer to each question.

1. (001) What do the first two digits of the Air Force Specialty Code (AFSC) 32551 identify?

   a. Avionics Instrument Systems.
   b. Avionics Systems Career Field.
   c. Instrument Systems Career Field.
   d. Avionics Instrument and Automatic Flight Control Systems.

2. (001) What does the third digit of the Air Force Specialty Code (AFSC) 32551 identify?

   a. Avionics Systems.
   b. Instrument Systems.
   c. Avionics Instrument Subdivision.
   d. Automatic Pilot/Instrument Subdivision.

3. (002) In what two ways must you demonstrate proficiency on the job as an Avionics Instrument Systems Specialist before you can be upgraded to the 5-skill level?

   a. Perform duty at the 5-skill level for at least 6 months and be recommended by your commander.
   b. Perform duty at the 5-skill level for at least 9 months and be recommended by your commander.
   c. Perform duty at the 5-skill level for at least 6 months and be recommended by your supervisor.
   d. Perform duty at the 5-skill level for at least 9 months and be recommended by your supervisor.

4. (002) What three types of AFSCs, in addition to the awarded AFSC, does the Air Force use for your career field?

   a. Primary, Control, and Duty.
   b. Craft, Master, and Endowed.
   c. Directed, Primary, and Assigned.
   d. Control, Technical, and Qualification.

5. (003) Which of the following validated factors in the Weighted Airman Promotion System (WAPS) reflects your demonstrated capabilities in daily actions?

   a. Specialty Knowledge Test (SKT).
   b. Promotion Fitness Exam (PFE).
   c. Airman Performance Report (APR).
   d. Time in Service (TIS).

6. (004) Which organization is responsible for determining the skill requirements for training?

   a. Extension Course Institute (ECI).
   b. Air Training Command (ATC).
   c. Each training section.
   d. Air University (AU).

7. (005) Upgrade training is designed to

   a. advance an airman's AFSC skill level.
   b. increase an individual's career knowledge only.
   c. increase knowledge and skill in an awarded AFSC.
   d. help an individual earn an AFSC not in the normal progression pattern of the individual's present AFSC.

8. (006) The purpose of the dual-channel OJT program is to provide an airman with both

   a. skill and experience.
   b. skill and proficiency.
   c. knowledge and experience.
   d. knowledge and job proficiency.

9. (007) Name the type of training which involves courses taught by ATC on a recurring basis at an ATC installation and includes basic, lateral, advanced, and supplemental training.

   a. Field Training, Type 4.
   b. Resident Regular, Type 3.
   c. ATC Resident Special, Type 2.
   d. Special Contract, Type 1.

10. (008) AFM 50-5, USAF Formal Schools Catalog, Volume I, contains which of the following aids to the supervisor?

    a. Course announcements.
    b. Clothing and equipment tables.
    c. Explanation of training terms.
    d. Instructions for completing AF Form 403, Request for Special Training.

11. (009) Which one of the following options is not a category of ECI courses?

    a. Specialized.
    b. Career Development.
    c. Officer Candidate Training.
    d. Professional Military Education Program.

12. (010) What Air Force program authorizes airmen to go TDY up to one year to complete all course requirements for a degree program?

    a. Operation Bootstrap.
    b. ECI Correspondence Courses.
    c. Professional Military Education.
    d. Community College of the Air Force.

13. (011) When is the initial evaluation of the training needs of a newly assigned airman required?

- a. Within 30 days of arrival at workcenter.
- b. Within 20 days of arrival at workcenter.
- c. At the time the airman reports for duty.
- d. Within 20 workdays of arrival at base.

14. (011) After the initial evaluation is complete, when is the next evaluation due?

- a. When new equipment is assigned to the unit.
- b. When unit training schedules it.
- c. It is a continuing process.
- d. When the JPG is reviewed.

15. (012) Which one of the following airmen is most likely to be chosen for retraining in another career field?

- a. One in career status.
- b. One from a shortage AFS.
- c. One who is on a directed duty assignment.
- d. One who is considered surplus in the career field.

16. (013) Which one of the following sources is not normally used for planning future OJT requirements?

- a. Unit Manning Document (UMD).
- b. Program Technical Training (PTT), Volume 2.
- c. A major command's system of personnel forecasts.
- d. Documents projecting the basic change in mission requirements.

17. (014) Realistic on-the-job training may be impractical or impossible because of temporary conditions or

- a. lack of CDCs.
- b. local situations.
- c. lack of training aids.
- d. Air Force directives.

18. (014) For a training capability to exist, there must be

- a. a person technically qualified to perform the task under consideration.
- b. a trainer with the same or higher skill level.
- c. an individual to certify job proficiency.
- d. a qualified technician as a trainer.

19. (015) Upon completion of classification policy requirements and training, an airman should be immediately

a. awarded the new AFS skill level.
b. permitted to demonstrate proficiency.
c. considered for award of the appropriate AFSC.
d. entered into training for the next higher skill level.

20. (016) If an airman who has been removed from UGT for failure to progress does not concur with the withdrawal, what action must be taken?

a. Initiate retraining orders into another AFS.
b. Return airman to a previously awarded AFS.
c. Schedule a classification board hearing.
d. Continue the airman in training.

21. (017) All upgrade trainees must use which one of the following items for career knowledge training?

a. Local JPGs.
b. CDCs, if available.
c. STS study/technical references.
d. Appropriate technical orders (TOs).

22. (017) CDCs are written to provide the trainees with sufficient information to satisfy the

a. knowledge requirements in the STS.
b. proficiency requirements specified for the job.
c. task requirements specified in the dual channel OJT concept.
d. knowledge and proficiency requirements specified in the STS and JPG.

23. (018) A point the supervisor should stress during issuance of CDC materials to a trainee is the

a. importance of VRE scores.
b. supervisor's responsbility.
c. parallel proficiency training.
d. essentiality of the CDC for career progression.

24. (019) A supervisor should document the results of a trainee's supervised study of "weak" areas of CDC on the

a. Study Reference Guide.
b. AF Form 1096, CDC Status Record.
c. ECI Form 9, Report of VRE (or CE).
d. AF Form 623a, On-the-Job Training Record Continuation Sheet.

25. (020) The PTT is the mission directive for accomplishing

a. military and technical training.
b. all formal Air Force training.
c. on-the-job training only.
d. technical training only.

26. (020) The supervisor can use the PTT, Volume II, Section IV, to find the listings of

a. CDCs being deleted.
b. all CDCs being developed.
c. CDCs and ECs for voluntary enrollees.
d. all CDC requirements applicable to an AFS.

27. (021) Bypassed specialists are airmen who are awarded the semiskilled level of an AFS based upon

a. previous military or civilian training, education, or experience.
b. prior active services in other military services.
c. skills gained through on-the-job training.
d. demonstrated aptitudes for a required AFS.

28. (022) Qualified airmen whose control AFSC is indicated as an overage

a. must be retrained.
b. are encouraged to retrain.
c. must be returned to previously awarded AFSC.
d. must be discharged if they are first-term airmen.

29. (023) The specialty training standard (STS) is defined as

a. an on-the-job training guide.
b. the official Air Force specifications for training.
c. a document containing tasks for all Air Force AFSCs.
d. the official ATC specification for technical training.

30. (024) An "X" in column 2A of an STS indicates that no training is given in the basic course because

a. of limitations in resources.
b. training must be gained on the job.
c. no proficiency is required at this level.
d. the student has previous training on this task.

31. (025) What are the contents of column 1 of the STS?

a. Duties required of the specialty.
b. Tasks, knowledges, and study references.
c. Proficiency level, progress record, and certification.
d. Proficiency levels for the 3-, 5-, and 7-skill levels.

32. (026) While reviewing and coordinating on a tentative STS, you should consider the fact that the STS is directed toward the

a. specialty and the job.
b. job, not the specialty.
c. specialty, not the job.
d. total Air Force requirements.

33. (027) Individual units would be likely to duplicate an airman's training were it not for Air Force policy on

a. OJT manager's control of training.
b. individual control of records.
c. centralized records.
d. recording training.

34. (027) If upgrade trainees are transferred before being upgraded, they must handcarry all CDC materials except the

a. VREs and CE.
b. course examination (CE).
c. "Key," workbooks, and VRE.
d. volumes not yet completed.

35. (028) The OJT advisory service has the responsibility of

a. training OJT supervisors in OJT methods.
b. training personnel on OJT for the ANG/AFRES.
c. advising trainers of OJT methods and responsibilities.
d. assisting commanders in establishing effective OJT programs.

36. (029) How should the supervisor indicate on the JPG that training has started on a required task?

a. Enter the date in Column A.
b. Enter the date in Column B.
c. Circle the applicable task verb.
d. Have the trainee initial and date the task.

37. (030) How is qualification training recorded?

a. On the JPG, in the same manner as UGT.
b. On the JPG, with tasks identified by the letter "q."
c. As a listing of tasks on AF Form 797, JPG Continuation Sheet.
d. As a special entry of AF Form 623a, On-the-Job Training Record Continuation Sheet.

38. (031) Unless needed for recording current skill level training, JPGs for previous skill levels are

a. discarded.
b. given to the individual.
c. sent to CBPO-OJT unit for file.
d. put in a separate file and used to record qualification training.

39. (028) What must the supervisor do if a new or revised STS is received?

a. Review for command coordination.
b. Use it only if a new trainee is assigned.
c. Compare it with the JPG being used for training.
d. Convert it to a JPG and file it in the trainee's folder.

40. (028) The JPG should reflect tasks which are

a. shown on the annotated STS only.
b. those on which the trainee has already qualified.
c. recorded on AF Form 797, JPG Continuation Sheet only.
d. applicable to the trainee's position and skill level.

41. (029) AF Form 623, On-the-Job Training Record, is a

a. complete history of an airman's training.
b. comprehensive record of AFSC-oriented training.
c. record of upgrade and qualification training only.
d. broad record of all training, education, and experience.

42. (030) The AF Form 623 should be given to the individual

a. upon his or her promotion to E-8.
b. if needed for CCAF credits.
c. upon his or her separation from the Air Force.
d. in all of these situations.

43. (031) The supervisor uses AF Form 1096 to

a. record progress in proficiency training.
b. have a permanent record of CDC trainees.
c. evaluate the effectiveness of the trainer and trainee.
d. monitor progress in mandatory career development courses.

44. (031) The AF Form 1096, CDC Status Record, is maintained by the

a. unit OJT manager and the immediate supervisor.
b. squadron OJT manager only.
c. immediate supervisor only.
d. CBPO-OJT unit.

45. (031) Once the trainee has successfully completed the mandatory CDC(s), what must the supervisor do with the AF Form 1096?

a. Retain it in the training folder.
b. Forward it to the squadron OJT manager.
c. Remove it from the training folder and destroy it.
d. Keep it on file if the trainee needs further upgrade training.

46. (032) The AF Form 1098 is used to document

a. tasks which the supervisor relies on someone else to validate.
b. task qualifications of a critical nature.
c. tasks requiring recurring training.
d. all of these.

47. (035) You, as a supervisor, should dispose of AF Form 1098 when

a. the trainee goes PCS.
b. all entries are noncurrent.
c. the form is completely filled.
d. the tasks are transferred to the JPG.

48. (036) The MMICS printout called "Training Forecast" provides

a. an output portraying the status of individual training requirements.
b. a listing of a specific workcenter's scheduled training events.
c. an update of training data to an individual's training record.
d. a course status report for a specific course code.

49. (037) Which one of the following OJT responsibilities belongs to the supervisor/trainer?

a. Establish controls to ensure that OJT is recorded properly.
b. Develop the JPG as the basic training control document.
c. Forward application for mandatory CDCs to ECI.
d. Requisitioning STSs from PDO.

50. (038) To make sure that OJT trainees are enrolled in and complete all requirements of applicable CDCs is an OJT responsibility of the

a. squadron OJT manager.
b. immediate supervisor.
c. CBPO-OJT unit.
d. OJT trainer.

51. (039) Which of the following characteristics is the most important consideration for a supervisor in selecting an individual for the job of OJT trainer?

a. Patient with others.
b. Enjoy working with and teaching others.
c. Ability to evaluate a trainee's progress fairly.
d. Knowledgeable concerning the training duties of the job.

52. (040) Three steps that are helpful to stimulate an active learning situation are

a. instruction, practice, and evaluation.
b. motivation, performance, and testing.
c. motivation, instruction, and practice.
d. indoctrination, motivation, and instruction.

53. (040) Which one of the following actions should start when the trainer receives a trainee?

a. Evaluation.
b. Motivation.
c. Instruction.
d. Orientation.

54. (041) Which of the following choices reflects correct training principles?

a. Unknown to known, easy to difficult, and speed.
b. Known to unknown, difficult to easy, and speed.
c. Known to unknown, easy to difficult, and accuracy.
d. Unknown to known, easy to difficult, and accuracy.

55. (042) What teaching method promotes a two-way exchange of ideas during group instruction when the objective is to provide background information on procedures of common interest to the group?

a. Lecture.
b. Discussion.
c. Performance.
d. Demonstration.

56. (043) Helping the trainee to build self-confidence is a part of what OJT step?

a. Present the operation to the trainee.
b. Prepare the trainee for instruction.
c. Prepare the training situation.
d. Tryout performance.

57. (043) "Use available training aids" is a part of which step of an effective OJT technique?

a. Prepare the training situation.
b. Tryout performance by the trainee.
c. Prepare the trainee for instruction.
d. Present the operation to the trainee.

58. (044) What determines how far a task should be broken down for job instruction purpose?

a. Local directives.
b. JPG knowledge levels.
c. Trainee's experience and ability.
d. Trainer's experience and ability.

59. (045) The result of an effective OJT program should be

a. increased production.
b. better training methods.
c. accurately maintained charts and records.
d. trainees with a genuine interest in training.

60. (046) The field evaluation program provides a source of information to determine the

a. need to update the JPG.
b. need to revise the approved STS.
c. extent to which graduates are promoted.
d. extent of on-the-job training effectiveness.

61. (047) Where can the methods and procedures for the protection of vital defense information be found?

a. AFR 205-1 & DOD 5200.1-R.
b. AFR 66-1 & DAF 5200.1-R.
c. AFM 205-1 & DOD 3303.3-R.
d. AFM 66-1 & DOD 5200.1-M.

62. (047) The DOD and Air Force security regulations can best be described as

a. specific guidelines with limited application.
b. directive in nature and applicable Air Force wide.
c. vague guidelines for establishing a security program.
d. optional guidelines for use at the major command level.

63. (048) Information is classified according to its

a. user.
b. location.
c. application.
d. importance.

64. (048) Unauthorized disclosure of which of the following information could result in hostilities against allies of the United States?

a. Secret.
b. Official.
c. Top Secret.
d. Confidential.

65. (049) What term identifies information that is withheld from the general public?

a. Official.
b. Classified.
c. Categorized.
d. Confidential.

66. (050) An important rule to remember when using the telephone is to

a. keep classified information brief and to the point.
b. avoid discussing classified matters on the telephone.
c. make sure the other person on the line has a need to know.
d. tell the other person the classification of the information.

67. (051) How are commander's call, telephone conversations, social gatherings, and radio transmissions best described as they relate to classified or sensitive information?

a. Security risks.
b. Security weaknesses.
c. Voice communications.
d. Unsecure transmissions.

68. (051) Which of the following best describes reasons why people violate good security practices when using the telephone?

a. Trapped by time, fear of rank, conducting personal business, and talking around a subject.
b. Trapped by time, talking around a subject, gossiping, calling home, and arranging a PCS move.
c. Fear of rank, conducting personal business, self-made reference systems, and arranging a PCS move.
d. Paraphrasing, using code words, becoming emotional, calling home, and conducting official business.

69. (052) The term "clandestine sabotage" means

a. spying openly.
b. spying secretly.
c. openly destroying equipment.
d. secretly destroying material.

70. (053) Which of the following statements best describes the restricted area exchange badge procedure?

a. It involves only one badge.
b. It requires the issuance of two badges.
c. It involves the notification of central security control.
d. Personnel are asked to sign their name which will be compared against their other credentials.

71. (053) Entry control procedures for restricted areas are designed for what reason?

a. To develop security measures for protecting nuclear weapons.
b. To identify those people who need access to the restricted area.
c. To deny unauthorized persons access to critical operational resources.
d. To monitor the number of authorized people entering the restricted area.

72. (054) What official document is used to identify individuals who have been granted unescorted entry authority to controlled areas of an Air Force installation?

a. Restricted area badge.
b. Security clearance.
c. Identification card.
d. Automotive decal.

73. (055) OPSEC involves the protection of

a. all classified information from disclosure to the enemy.
b. operational resources from clandestine sabotage attempts.
c. weapons, weapon systems including aircraft, and weapon storage facilities.
d. classified and unclassified information about a military operation that could aid the enemy if revealed.

74. (056) The safety directive AFR 127-101 does which of the following?

a. Establishes, clarifies, and supports Air Force safety programs.
b. Augments, clarifies, and supports other Air Force safety publications.
c. Augments, clarifies, and changes other safety publications.
d. Establishes, directs, and standardizes accident prevention programs.

75. (056) AFR 127-101 provides extensive coverage of which of the following safety areas?

a. Ground accident prevention.
b. Hazard identification.
c. Safety management.
d. Fire protection.

76. (057) Which of the following is not a supervisory responsibility?

a. Provide safety training.
b. Punish safety violators.
c. Provide protective equipment.
d. Enroll personnel in health maintenance programs.

77. (058) How can personal characteristics, in relation to safety, best be described?

a. Difficult to detect and easy to counteract.
b. Difficult to detect and difficult to counteract.
c. Easy to detect and easy to counteract.
d. Easy to detect and difficult to counteract.

78. (059) At what stage of a fire are fire extinguishers intended to be used?

a. During the 1st stage.
b. During the 2nd stage.
c. During the final stage.
d. During the progressive stage.

79. (059) What theory is the basis for extinguishing fires?

a. If the cause of the fire is eliminated, the fire will go out.
b. If one of the elements of combustion is removed, the fire will go out.
c. If the chemical reaction is slowed significantly, the fire will go out.
d. If the progress of the fire is retarded significantly, the fire will go out.

80. (060) What type of extinguisher would you use on an electrical fire in your shop?

a. Category 3.
b. 3rd degree.
c. Electrical.
d. Class C.

pg, (060) Water is used only on which type of fires?

a. Class A.
b. Chemical.
c. Category 2.
d. First degree.

82. (061) Where and how should lubricants and solvents be stored?

a. In metal containers, in the work area where they are accessible.
b. In approved metal containers, outside, and away from heat.
c. In sealed containers so they don't spill within the work area.
d. In ventilated containers, outside where fumes will disperse.

83. (061) What are the characteristics of a good solvent?

a. It should be nonvolatile, nonflammable, and cause minimum deterioration of components or insulation.
b. It should leave little or no residue with minimum deterioration of components or insulation.
c. It should clean and degrease thoroughly with minimum deterioration of components or insulation.
d. It should be nonvolatile, nonflammable, and as nontoxic as possible.

84. (061) What precaution should you take when using toxic solvents?

a. Avoid prolonged breathing of the vapors or fumes.
b. Have a qualified safety observer present.
c. Have periodic physical examinations.
d. Have a fire extinguisher available.

85. (062) What is the major cause of accidents and injuries when working with electronic equipment?

a. Overloading.
b. Shot circuits.
c. Unfamiliarity.
d. Poor judgement.

86. (063) Prior to using compressed air, what action should you take?

a. Get a safety observer to stand by.
b. Clear all personnel from your work area.
c. Notify your shift supervisor and job control.
d. Inspect the air lines and connections for defects.

87. (064) Why do injuries occur in the manual handling of equipment?

a. Personnel use poor handling techniques.
b. The equipment is too bulky to handle safely.
c. Personnel fail to use hand trucks properly.
d. Individuals attempt to lift heavy objects by themselves.

88. (065) Who is held primarily responsible for unsafe conditions caused by poor housekeeping practices in your work center?

a. Each of you assigned to the work center.
b. The work center supervisor.
c. The shift supervisor.
d. The squadron commander.

89. (065) How should you remove flammable liquids which are spilled in the shop?

a. Flush with water and mop it up.
b. Use compressed air to help dry it up.
c. Mop with paper towels or absorbent rags.
d. Mop with noncombustible absorbent materials.

90. (065) Where may you safely store extra flammable cleaning supplies and materials?

a. Under outside stairways protected from the elements.
b. In closed metal containers detached and away from the building.
c. In metal containers on the roof of the building if the roof is flat.
d. In metal utility lockers attached to the building so they won't be blown over.

91. (066) What does the term "electromagnetic radiation" refer to and what is its source?

a. Nuclear radiation emitted by magnetrons.
b. Avionics radiation emitted by electronic equipment.
c. High frequency magnetic interference emitted by electrical power generators.
d. Radiation emitted by high frequency radio transmitters, radar, or electronic counter measure devices.

92. (067) When should the hydraulic system be depleted, danger tags hung on the controls, and the moveable surfaces be locked in position?

a. When severe weather, such as high winds, threatens to damage the aircraft.
b. Prior to jacking and leveling the aircraft to adjust the inclinometer.
c. When you are working in the area of the power actuated surfaces.
d. Prior to operationally checking the power actuated system.

93. (068) Nuts, bolts, screws, tools, pieces of safety wire, etc., found loose on the flight line are referred to as what?

a. Fallen objects.
b. Foreign object damage.
c. Aircraft common hardware.
d. Normal maintenance residue.

94. (069) The suction effect of a jet engine at the intake is

a. equal and opposite to the blowing effect of the exhaust and more dangerous.
b. sufficient to cause fatal injury to personnel and damage to equipment.
c. is often used to vacuum the surface of the flight line.
d. the means of propelling jet aircraft through the air.

95. (070) Which of the following is a safe use for maintenance stands?

a. Having loose tools and light equipment on a raised platform.
b. Standing on a lower guard rail to extend your reach.
c. Providing work platforms at variable heights.
d. Standing on the ladder to raise the platform.

96. (071) The two general classes of Air Force publications are

a. organizational and intermediate.
b. specialized and miscellaneous.
c. rules and regulations.
d. departmental and field.

97. (072) How can Air Force publication indexes be identified?

a. Double zero (00) is the first part of the publication number.
b. Zero (0) is the first digit of the publication number.
c. The publication number is preceded by AFPI.
d. The publication number is preceded by AFI.

98. (072) In the double numbering system used to reference and control Air Force publications, the first number shows the

a. basic subject and the second number shows the specific area.
b. index and the second number shows the basic subject covered.
c. general classification and the second number shows the subdivision.
d. specific subject covered and the second number shows the issuing command.

99. (073) Looking in the index (AFR 0-2) for AFR 39-29, Promotion of Airmen, you notice that someone has placed a plus sign (+) in front of the number. What does this sign tell you?

a. This regulation is needed in addition to those already available.
b. An obsolete copy is available and a current copy is on order.
c. Extra copies are available for loan.
d. A current copy is available.

100. (074) What section is charged with keeping a regulation or manual up to date?

a. Quality Control (QC).
b. Office of Primary Responsibility (OPR).
c. Air Force Publications Center (AFPC).
d. Central Publications Office (CPO).

101. (075) The first part of the TO number identifies the

a. TO category.
b. Kind of TO.
c. TO series.
d. Aircraft model.

102. (076) You need the performance characteristics of an aircraft to verify the proper operation of your system. What aircraft technical manual would give this information?

a. Maintenance manual.
b. Inspection manual.
c. Operation manual.
d. Flight manual.

103. (077) Which type of TOs provide information and instructions in various subject areas for supervisory and administrative personnel?

a. Methods and Procedures TOs.
b. Operation and inspection manuals.
c. Indexes, guides, and directories.
d. Job Guides and Maintenance support TOs.

104. (078) In what type of TCTO would the action necessary to correct an unsafe condition be directed and outlined?

a. Immediate action TCTO.
b. Urgent action TCTO.
c. Serious action TCTO.
d. Routine action TCTO.

105. (079) Numerical indexes and requirement tables (NI&RTs) are TO indexes which are based on

a. part number or type number.
b. the first part of the TO number.
c. federal stock number or national stock number.
d. functional usage or family grouping of equipment.

106. (080) The purpose of abbreviated technical orders is to

a. reduce the bulkiness of technical manuals.
b. update technical information.
c. provide pictorial guidance.
d. simplify work procedures.

107. (081) What method is used to incorporate, augment, or revise data when there isn't time to preprint a basic TO?

a. A supplement is issued.
b. A revision is issued.
c. An appendix is issued.
d. An addendum is issued.

108. (082) What type of publication is prepared in limited quantities to test and verify procedures developed for use with the first or early production models of Air Force equipment?

a. Methods and Procedures TOs.
b. Time Compliance TOs.
c. Preliminary TOs.
d. Abbreviated TOs.

109. (083) What publications are available to help you identify the correct TO for equipment when you know the subject or the name, the part number, or the type number of the equipment?

a. Indexes.
b. Addendums.
c. Appendices.
d. Tables of contents.

110. (084) A violation of a "warning" statement in a TO could result in

a. serious injury or death.
b. damage to the aircraft or equipment.
c. a compromise of defense information.
d. improper equipment operation or test results.

111. (085) How are technical order improvement reports routed for evaluation?

a. From TO user to shop chief to major command to Headquarters, Air Force.
b. From TO user to shop chief to quality control to major command to AFLC depot.
c. From TO user to shop chief to branch chief to quality control to major command to Headquarters, Air Force to AFLC depot.
d. From TO user to quality control to chief of maintenance to major command to Headquarters, Air Force to AFLC depot to civilian contractor.

112. (086) What information is contained in Section I of the Illustrated Parts Breakdown (IPB)?

a. General information about IPB technical orders.
b. Information needed in order to use the IPB properly.
c. Table of contents, introduction, and reference designator listing.
d. A breakdown list of major assemblies accompanied by an illustration of the major assembly breakdown.

113. (087) Section II of an IPB, the Group Assembly Parts list, contains

a. a complete description of the parts in an assembly including the manufacturer's address.
b. a description of the parts in an assembly including size, color, and cost of each.
c. a breakdown list of major assemblies accompanied by an illustration of the major assembly breakdown.
d. breakdown illustrations of major assemblies, description of parts including stock number, source, and cost.

114. (088) What information is contained in Section III, Numerical Index, of an IPB?

a. Part numbers listed in alphanumerical sequence.
b. Reference designators listed in numerical sequence.
c. Part numbers and stock numbers listed in numerical sequence.
d. Part numbers and reference designators listed in alphanumerical sequence.

115. (089) What is the purpose of Section IV, the Reference Designation Index, of the IPB?

a. It provides a fast way to cross-reference component part numbers to aircraft station numbers.
b. It provides a fast way to cross-reference manufacturer's technical reference to Air Force terminology.
c. It provides a fast way to cross-reference information in dash two (-2) maintenance manuals to part numbers, figure, and index numbers.
d. It provides a fast way to cross-reference between TO wiring diagrams and the figure and index numbers in the Group Assembly Parts List (Section II).

116. (090) Wiring diagram manuals are used

a. in conjunction with job guides and checklists.
b. in conjunction with systems operating instructions.
c. in conjunction with troubleshooting diagrams or charts.
d. to identify components, wiring, and signal flow in electrical circuits.

117. (091) What does the circuit function letter "E" indicate?

a. Exhaust temperature thermocouple wiring.
b. Engine instrumentation wiring.
c. Extra wiring for future use.
d. Environment systems wiring.

118. (092) Where can you find a complete list of every switch, terminal block, connector, and splice area used on an aircraft?

a. In the equipment inventory.
b. In the List of Applicable Publications (LOAP).
c. In the organization maintenance manuals on Avionics systems.
d. In the Designation Cross-Reference of the Wiring Diagram Manual.

119. (093) The aircraft location of each item listed or shown in wiring diagram manuals is shown by

a. station numbers.
b. station numbers or location drawings.
c. station numbers or location drawings and IPB illustrations.
d. station numbers or location drawings, IPB illustrations, and IE & RTs.

120. (120) Wiring diagrams in wiring diagram manuals show

a. block diagrams of every system.
b. internal wiring of system's components.
c. signal flow diagrams for troubleshooting systems.
d. complete wiring connections from component to component.

121. (095) Which of the following is not a function of NI&RTs?

a. Determining the distribution of TOs.
b. Up-dating TO files and records.
c. Assigning security classifications to TOs.
d. Determining requisition requirements of TOs.

122. (096) Where are subaccounts listed on the AFTO Form 110 card?

a. Line A.
b. Line B.
c. Line C.
d. Line D.

123. (097) Supplement checks on TO files consist of

a. reviewing all NI&RT supplements for currency.
b. insuring that all supplements are properly filed.
c. insuring that all required supplements are in the TO file.
d. comparing TO files and records against new NI&RT supplements for currency.

124. (098) How are TOPS data pages filed?

a. In front of the TO in reverse numerical order.
b. In front of the TO in numerical order.
c. Facing the changed page.
d. Behind the basic TO.

END OF EXERCISE

MAIL TO: ECI, GUNTER AFS AL 36118-5643

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I **CORRECTED OR LATEST ENROLLMENT DATA**

1. THIS REQUEST CONCERNS COURSE (1-6)	2. TODAY'S DATE	3. ENROLLMENT DATE	4. AUTOVON NUMBER
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8. ADDRESS
OJT ENROLLEES: Address of unit training office with zip code.
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(33-53)
(54-75)

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9	Send course materials. (Specify in "Remarks") [ ] Not received [ ] Lost [ ] Damaged
10	Course exam not yet received. Final VRE submitted for grading on ________ (date).
11	Results for VRE Vol(s) 1 2 3 4 5 6 7 8 9 10 not yet received. Answer sheet(s) submitted ________ (date).
12	Results for CE not yet received. Answer sheet submitted to ECI on ________ (date).
13	Previous inquiry ([ ] ECI Fm 17, [ ] ltr, [ ] msg) sent to ECI on ________ (date).
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15	Other (Explain fully in "Remarks")

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☐ YES ☐ NO

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(Textual reference for the answer I chose can be found as shown below.)

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ON PAGE NO ____________

IN ☐ LEFT ☐ RIGHT COLUMN

LINES ________ THROUGH ________

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CDC 32551

AVIONICS INSTRUMENT SYSTEMS SPECIALIST

(AFSC 32551)

Volume 2

Specialty Administration and Aircraft Familiarization

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DEPARTMENT OF THE AIR FORCE
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UNITED STATES OF AMERICA

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THIS PUBLICATION HAS BEEN REVIEWED AND APPROVED BY COMPETENT PERSONNEL OF THE PREPARING COMMAND IN ACCORDANCE WITH CURRENT DIRECTIVES ON DOCTRINE, POLICY, ESSENTIALITY, PROPRIETY, AND QUALITY.

Preface

THIS SECOND volume of CDC 32551, Avionics Instrument Systems Specialist provides you with information about the Air Force supply system and procedures, data collection and reporting, maintenance management, supervision, and aircraft familiarization.

Technical references and a bibliography are provided so you can keep abreast of changes as they occur.

Code numbers appearing on figures are for preparing agency identification only and should be of no concern to the student.

Direct your questions or comments relating to the accuracy or currency of this volume to the course author: 3360 TCHTG/TTGU–F, ATTN: MSgt Lawrence B. Miller, Chanute AFB IL 61868. If you need an immediate response, call the author, AUTOVON 862–2041, between 0730 and 1600 Central Standard Time, Monday through Friday. *(NOTE: Do not use the suggestion program to submit changes or corrections for this course.)*

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This volume is valued at 36 hours (12 points).

Material in this volume is technical accurate, adequate, and current as of August 1981.

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CHAPTER 1

NOTE: In this volume, the subject matter is developed by a series of Learning Objectives. Each of these carries a 3-digit number and is in boldface type. Each sets a learning goal for you. The text that follows the objective gives you the information you need to reach that goal. The exercises following the information give you a check on your achievement. When you complete them, see if your answers match those in the back of this volume. If your response to an exercise is incorrect, review the objective and its text.

Supply

THE AIR FORCE spends billions of dollars every year for necessary operational resources such as men, materials, and services. The Air Force must justify its total resource requirements when our budget is presented to Congress. This budget is based on the combined needs of each major command; each of which considers the needs of all units within the command, including every airman, aircraft system, and support equipment.

Congress very rarely gives the Air Force, or any other defense agency, all that it asks for. Of the defense money received, each squadron in the Air Force is provided enough, hopefully, to meet its operational obligations. It seems as though there is never enough for the nice-to-have items that would make our jobs easier or our military environment more bearable; therefore, we cannot afford to be careless with any of our resources.

To do our jobs, accomplish the mission of our sections, and accomplish the mission of the Air Force, we buy many thousands of items such as spare parts, tools, maintenance equipment, pencils, and even paper clips. This property is stored, issued, reclaimed; and reissued and the cycle may be repeated many times as we attempt to stretch our Air Force dollars enough to do our jobs. In this section, we discuss some ways of using our supplies effectively.

1-1. Supply Discipline

All airmen, officers, and civilian employees must protect and treat government property as if it were their own. When you use a piece of government property, it is like borrowing a book from the library. Sooner or later you must return it, and you are the one who is obligated to take care of it.

It is important that you clearly understand your responsibility for Government property. You may have to pay for a piece of equipment you have damaged. Although you pay for it, you won't get to keep it. Many other regulations govern property responsibility. Your knowledge of rules and procedures can relieve you from monetary responsibility for the damange or loss of Air Force property.

Good business practice is important. Obtaining more supplies than you need to do your job is not good business practice. You do not purchase four additional spare tires for your automobile merely because it has four wheels. Neither is it necessary to buy a spare engine—the original engine should operate for more than 50,000 miles.

Follow these same practices when you obtain supplies for your shop. They are called the principles of supply discipline. You should know and practice these principles.

200. State why responsibility and accountability for Air Force property are assigned and name the governing directive.

Responsibility for Public Property. The property you must use in your duties (whether it is a desk, a toolkit, a truck, or an electronic test stand) is your responsibility. Good management dictates that the person who is using the property should be responsible for its care. Everyone in the Air Force is responsible for some type of property. For one person, it is a shop full of equipment; for another, a blanket. Property responsibility is part of any position in the Air Force.

Because the Air Force is large and complex, responsibility for its property must be assigned. Otherwise, it could never be sure that the property would be adequately safeguarded, and the whole system would fall into wastefulness and carelessness. Let us first determine where responsibility originates.

The money used to buy Air Force property comes from all of us in the form of taxes. The title to this property is not held by any one individual but is jointly held by all of us. You have no problem finding who is responsible for a personal item. You know that if you abuse your personal property, you will have to pay for its repair or replacement. Who, then, is responsible for the millions of Air Force items costing billions of dollars? Congress has the responsibility of appropriating the money to buy this property; Congress also passed the law to hold individuals responsible for public property.

Congress passed such a Federal law in March 1894 authorizing regulations concerning responsibility for public property. The Air Force explains the application of this in AFR 67-10, *Responsibility for Management of Public Property in Possession of the Air Force*. The officers, airmen, and civilian employees who are designated as supervisors are responsible for carrying out the orders and directives of the commander, and they have certain responsibilities for subordinates and property. However, if you are supervising several workers, you cannot always be looking over the shoulder of each worker. Like the commander, the supervisor cannot be solely responsible for the property in your activity.

In your duty section, you, your supervisor, and your commander have the responsibility for the property you are using. If this property should be damaged, the circumstances will determine who is responsible for the damages.

Property responsiblity is imposed by law on all officers, airmen, and civilian employees and cannot be delegated—only shared. This obligation includes *pecuniary liability*. This means that the individual must make good the loss, destruction, or damage of property caused by maladministration or negligence, regardless of duty assignment or level of command or supervision. Depending on the circumstances, any person, military or civilian, can be charged with one or more of three types of responsibility: command, supervisory, and custodial. When you buy an article from a store, the moment the sales clerk completes the transaction, the store drops its accountability. It then becomes your property and your responsibility.

Similarly, when a stock clerk issues an Air Force item to you, accountability is dropped insofar as the issuing authority is concerned. However, you do not become the owner of the item. Instead, the Air Force retains ownership of the item and you assume responsibility for its care and protection. Stated in other words, the property you use in your duties is your responsibility. It is important to note that property responsibility is in no way lessened by the fact that the issuing authority has terminated its accountability.

Exercises (200):

1. Why is responsibility for Air Force equipment assigned to individuals?

2. Identify the Air Force directive that explains the application of the law dealing with responsibility for public property.

3. Who has the responsibility, accountability, and ownership of the kit of tools used on the job?

201. Point out the ways that commanders exercise their responsibilities for equipment and other property.

Command Responsibility. Commanders at all levels have command responsibility for all the property under their jurisdiction. They are not exempt from pecuniary liability for the loss, damage, or destruction of Government property within their command.

Commanders must make sure that property records of supply transactions are kept accurately. To fulfill this duty, they must rely upon the people in their command. They must know which records must be maintained and how to maintain them. Though it is impossible for a commander to know all the minute details required for recordkeeping, the commander can make sure that the people filling these positions are trained and trustworthy.

Commanders should set an example for those under their command. The supplies and equipment assigned to them should be used for their intended purpose and not be wasted. The commander or representative must make frequent visits to the base activities to be certain that all property is receiving proper care and is being properly safeguarded. Although AFR 67-10 states that these visits be made often, the time intervals are not stated. When the activity is operating smoothly, the visits may not need to be as frequent.

To discharge their property responsibilities, the commanders issue instructions and directives that should be timely enough to take care of any changes in the mission of their command.

Exercises (201):

1. The wing commander has just called the squadron commander and informed him or her that a squadron maintenance truck is sitting in front of the base exchange full of people and that a similar occurence will result in all trucks being assigned to the regular motor pool. Why is the wing commander so concerned with the maintenance truck?

2. State ways commanders can discharge their responsibilities to those that serve under them.

202. State the conditions in which supervisory responsibility must be assumed.

Supervisory Responsibility. Supervisors usually work near the property for which they are responsible. Although

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they may not have as many responsibilities as the commander, they have more direct control over the property. Supervisory responsibility, discussed in AFR 67–10, applies to any person who exercises supervision over property whether it is being received, in use, in transit, in storage, or undergoing modification or repair. It covers the property from the time the Air Force buys it until it is consumed or sold.

If personnel are working directly under the supervision of the commander, the commander has supervisory as well as command responsibility for the Air Force property used. The supervisor must insure that subordinates know the appropriate local directives as well as the command publications and that they are trained in supply discipline.

Exercises (202):

1. State the condition in which a person must assume supervisory responsibility over equipment and supplies.

2. State the condition under which the commander has supervisory responsibility, as well as command responsibility, over property.

203. State the conditions under which custodial responsibility must be assumed.

Custodial Responsibility. Custodial responsibility is the responsibility that must be assumed when an individual acquires the physical possession of Government property. The word "custodian" means caretaker. A custodian is personally responsible for taking care of such property if the property is:

a. Issued for official or personal use, whether or not a receipt was signed for it.

b. Under the custodian's direct control for storage, use, custody, or safeguarding.

c. Found (indicating possible loss, theft, or abandonment) under circumstances requiring such personal care, custody, or protection.

Property issued to an individual does not become private property by the act of issue (whether the issue was for official or personal use). It remains at all times public property and, as such, must be adequately safeguarded.

A person may, and often does, have more than one type of responsibility. For example, for the office desk and chair, the commander has both command and custodial responsibility. A supervisor of a secretary has supervisory responsibility for the desk and other office equipment used by the secretary. The supervisor also has custodial responsibility for the desk and office equipment he or she personally uses. From these examples, you can see that many conditions could place more than one type of responsibility with the same individual.

If a person finds public property, he or she is responsible for its care and protection until it can be returned to the responsible person. The property must be placed back into the supply channels.

Exercises (203):

1. Under what conditions must you assume custodial responsibility for Air Force equipment?

2. While you are following a supply truck loaded with small boxes, you see two boxes fall off the truck. What actions are required of you?

204. State the methods used to relieve a person of property responsibility and the factors that must be considered.

Relief from Property Responsibility. We have mentioned the circumstances under which you must assume property responsibility. How can you be relieved of property responsibility? The condition of the property is an important factor when you are being relieved of responsibility for it. It may be serviceable; it may be unserviceable through fair wear and tear; or it may be lost, damaged, or destroyed. Pecuniary liability is usually involved when you are being relieved from the responsibility for property that you have lost, damaged, or destroyed. (Pecuniary liability means the responsible person must pay for the loss.) The methods of relief from property responsibility depend upon whether or not the individual admits pecuniary liability. We will postpone our discussion of relief from property responsibility under these conditions. Instead, we will explain how to be relieved where pecuniary liability is not involved. There are two ways that this can be done—by turn-in or by transfer. These methods apply to property that is serviceable or unserviceable because of fair wear and tear.

Exercises (204):

1. What important factor must be considered before a person can be relieved of property responsibility?

2. What type of liability is involved when a person is being relieved of property that has been lost?

3. Give the two methods used to relieve a person of property responsibility when pecuniary liability is not involved.

205. Given specific supply situations, state the proper solution for each.

Turn-in. The turn-in of property means putting it back into the supply channels. If the property is not serviceable, it is transferred to the disposal unit. The disposal procedure depends on the property involved. Serviceable items are turned in for reissue. If you have an item signed out from EMO (equipment management office) and you don't need it, turn it in. Example: You have an adding machine that you no longer need; return it to EMO and pick up your receipt. If no one else in the organization has a requirement for the machine, EMO returns it to Supply. BaSe supply will see if another organization has a need for the machine. If there is no requirement for the machine, Base Supply will dispose of it. It will ship the adding machine to another base or depot or to the local redistribution and marketing activity.

Each of these transactions must be documented to relieve each individual of responsibility for the machine. Such transactions occur frequently. When the turn-in is properly documented, each individual is relieved of responsibility for the property. Now, how is relief from property responsibility obtained when property or people are transferred?

Property transfer. The transfer of property, as used here, means changing its physical location or user. If the user of the property is changed, custodial responsibility moves to the new user. For example, the commander wants and gets a new desk, so the old one is sent to a section that needs it. Custodial responsibility for the old desk then moves to the user in that section.

The physical location of an item carrying a serial number must be entered on property records. An example of transferring such an item is moving a typewriter from the orderly room to another section in the same organization. This type of transfer relieves the people in the orderly room of supervisory and custodial responsibilities. The command responsibility for the typewriter still remains with the squadron commander. Had the typewriter been transferred to another squadron, the commander would be relieved. Property responsibility goes with custody or jurisdiction.

Transfer of personnel. If a person is transferred but the property he or she has been using remains with the organization, the property responsibility also stays in the organization. Some of the items of property for which the individual had custodial responsibility may be returned to supply. The records and hand receipts are annotated to show these turn-ins so that the individual may depart from the base. Suppose that the individual is a supervisor and a replacement is not on base to sign for the remainder of the property. The next higher supervisor is normally held responsible for the property until the replacement arrives.

Exercises (205):

1. The shop supervisor wants personnel to turn in unserviceable parts as soon as possible. Why?

2. Your shop has 12 extra straight-back chairs because of personnel losses. Your supervisor wants to turn them in to EMO so that they can be issued to Master Sergeant Neaves, the shop chief in the next room who has a need for them. Why turn them in rather than transfer them?

3. The shop supervisor who had the account for the shop has died. Explain what would have to be done with the supply account.

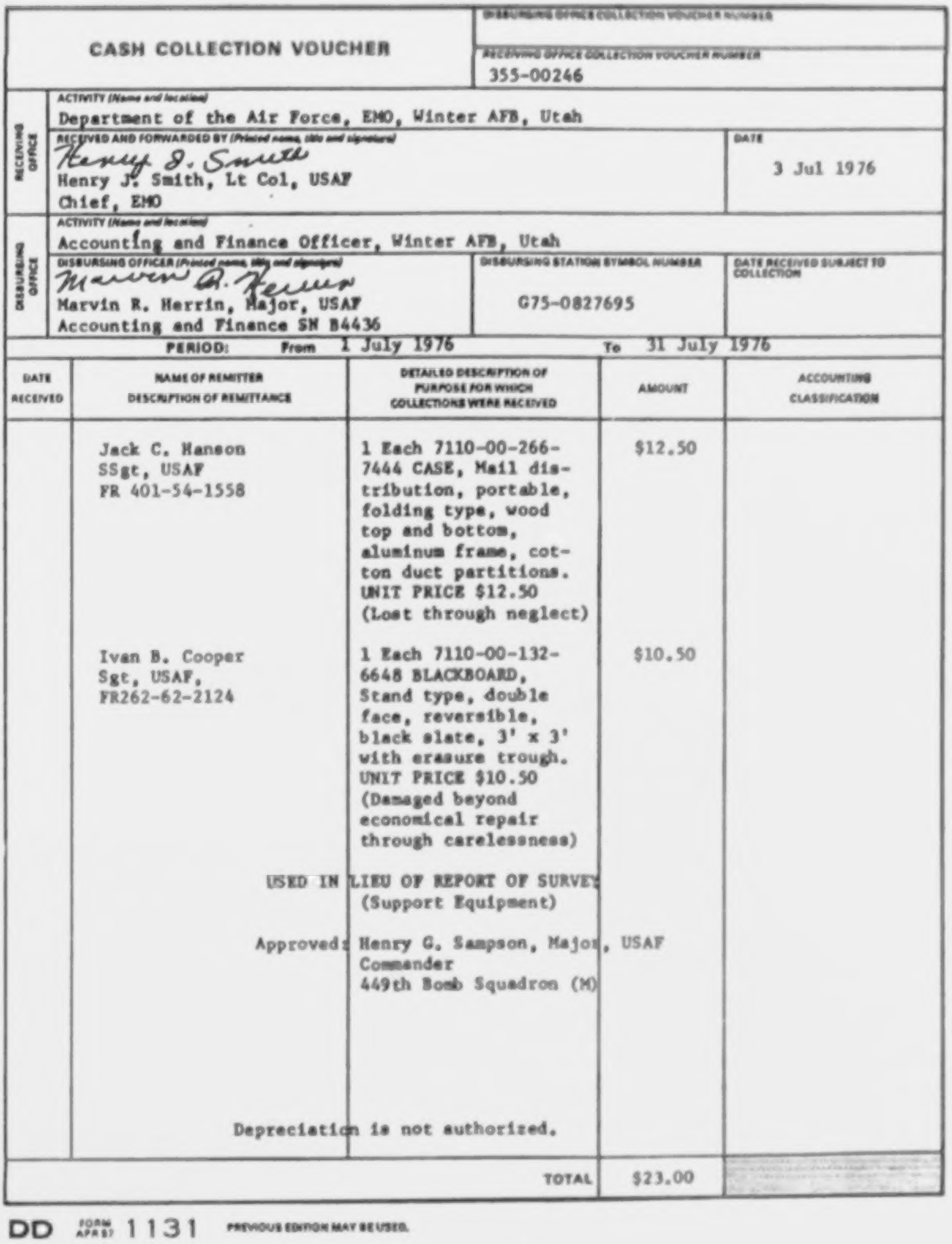
206. Define pecuniary liability and state the methods that are normally used for its relief.

When property is lost, damaged, or destroyed, its monetary loss to the Air Force must be accounted for in some manner. Either the person(s) with responsibility for the property must reimburse the Air Force or the Air Force must stand the loss. Now let us see how you may be relieved of responsibility for property that is lost, damaged, or destroyed. First, you must understand the term pecuniary liability.

Pecuniary Liability. Pecuniary liability applies to all personnel with property responsibility. It means that they must make good the loss caused by their maladministration or negligence. Pecuniary liability may be shared by persons having command, supervisory, and custodial responsibility; and even though an individual has paid for the loss, the property does not become that person's personal property.

Two methods of relief are the cash collection voucher and the statement of charges. These two methods are used to reimburse the Air Force when pecuniary liability is admitted and the damage to the article or its list price does not exceed $250.

Cash collection voucher. The least troublesome way to settle a monetary obligation is to pay in some form of cash. The Cash Collection Voucher, DD Form 1131 (fig. 1-1), is generally prepared by the responsible officer to cover the cash collections for a particular period of time. Listed on the cash collection voucher are the names of the airmen, the articles lost or damaged, and the amounts involved. The voucher shows the complete Air Force description of the items involved and the purpose for which collection was made. Negligence and carelessness may be given as the causes of the damage to the property. The statement "Used in Lieu of Report of Survey" indicates that pecuniary liability has been admitted. Before the money is turned in to



CASH COLLECTION VOUCHER

DISBURSING OFFICE COLLECTION VOUCHER NUMBER

RECEIVING OFFICE COLLECTION VOUCHER NUMBER 355-00246

RECEIVING OFFICE

ACTIVITY (Name and location) Department of the Air Force, EMO, Winter AFB, Utah

RECEIVED AND FORWARDED BY (Printed name, title and signature)
Henry J. Smith
Henry J. Smith, Lt Col, USAF
Chief, EMO

DATE 3 Jul 1976

DISBURSING OFFICE

ACTIVITY (Name and location) Accounting and Finance Officer, Winter AFB, Utah

DISBURSING OFFICER (Printed name, title and signature)
Marvin R. Herrin
Marvin R. Herrin, Major, USAF
Accounting and Finance SN B4436

DISBURSING STATION SYMBOL NUMBER G75-0827695

DATE RECEIVED SUBJECT TO COLLECTION

PERIOD: From 1 July 1976 To 31 July 1976

DATE RECEIVED	NAME OF REMITTER DESCRIPTION OF REMITTANCE	DETAILED DESCRIPTION OF PURPOSE FOR WHICH COLLECTIONS WERE RECEIVED	AMOUNT	ACCOUNTING CLASSIFICATION
	Jack C. Hanson SSgt, USAF FR 401-54-1558	1 Each 7110-00-266-7444 CASE, Mail distribution, portable, folding type, wood top and bottom, aluminum frame, cotton duct partitions. UNIT PRICE $12.50 (Lost through neglect)	$12.50	
	Ivan B. Cooper Sgt, USAF, FR262-62-2124	1 Each 7110-00-132-6648 BLACKBOARD, Stand type, double face, reversible, black slate, 3' x 3' with erasure trough. UNIT PRICE $10.50 (Damaged beyond economical repair through carelessness)	$10.50	

USED IN LIEU OF REPORT OF SURVEY
(Support Equipment)

Approved: Henry G. Sampson, Major, USAF
Commander
449th Bomb Squadron (M)

Depreciation is not authorized.

TOTAL $23.00

DD FORM APR 67 1131 PREVIOUS EDITION MAY BE USED.

Figure 1-1. DD Form 1131.

the finance office, the cash collection voucher must be approved by the individual's commander. The detailed procedures for preparing and processing this form are found in AFM 67-1, *USAF Supply Manual*, and other applicable directives. How does the individual make the payment if he or she does not have the money with which to pay?

Statement of charges. Airmen and civilian employees use DD Form 362, Statement of Charges for Government Property Lost, Damaged, or Destroyed (fig. 1-2), when pecuniary liability is admitted but a payroll deduction is desired in lieu of a cash payment. Like the cash collection voucher, the price of the damaged item cannot exceed $250.

The DD Form 362 contains two basic sections, the top section and the bottom section. The top section contains five basic columns. Two of these columns show the stock number and the nomenclature of the article. The quantity column is divided into seven subcolumns, used to identify (by number) the name(s) of the responsible individual(s) who are listed by name and SSAN in the lower section of the form. The remaining three columns in the top section give the total number of articles, the unit price, and the total price. In addition to the names of the responsible individuals, the lower section of the form contains columns showing the cause, the total charges, and the signature(s) of the responsible individual(s).

The individual(s) is charged with the actual cost of the articles or is given a percentage of depreciation (not to exceed 25 percent) authorized by AFM 177-111, *Accounting & Reporting of Government Property Lost, Damaged, or Destroyed.* Because of this depreciation, the charges may be less than the prices listed in the top section of the form. When the individual signs a statement of charges, he or she has made the following: (1) an acknowledgment, (2) an authorization, (3) a waiver of a right, (4) an affirmation, and (5) an agreement. The commander must certify this form before it is submitted for a payroll deduction.

If an officer admits pecuniary liability and cannot pay with cash, a DD Form 114, Military Pay Order, is used. This authorizes a pay deduction for the amount involved.

What action is taken for relief from property responsibility when pecuniary liability is not admitted? Also, what is done when the value of the property of the damage exceeds $250? This information will be covered under the next objective.

Exercises (206):

1. Define pecuniary liability.

2. Name the two methods used by the Air Force for reimbursement for lost, damaged, or stolen property valued at or below $250.

3. On the Cash Collection Voucher appears the following statement: Used in Lieu of Report of Survey. Why was this statement entered?

4. Why might there be a price of $200 listed at the top of a statement of charges form and a $185 price listed at the bottom?

5. Name some of the things an individual agrees to when he or she signs a statement of charges.

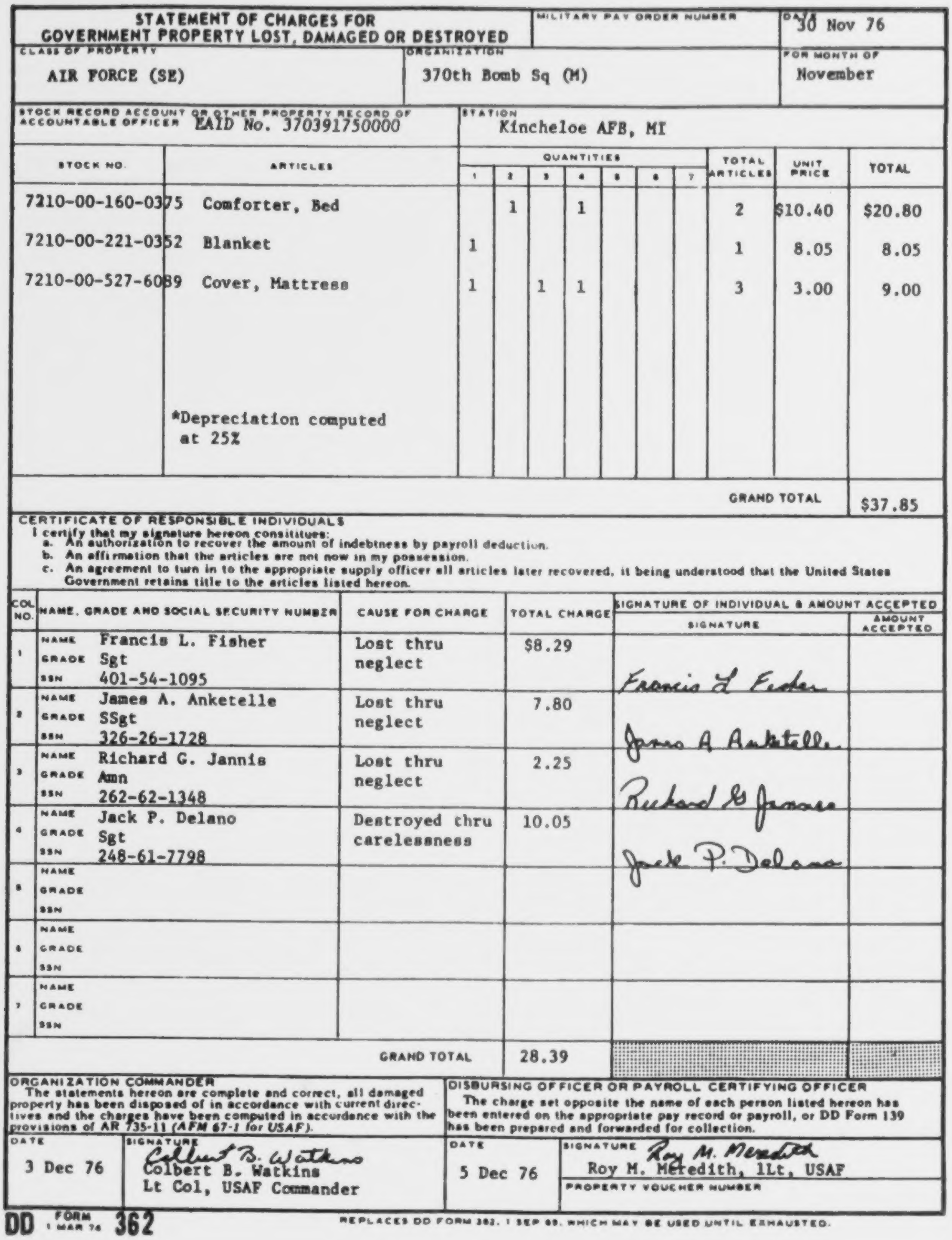
207. Point out important features of the report of survey.

Report of Survey (fig. 1-3). A GPLD (Government Property Lost or Damaged Survey Certificate, DOD Form 2090, is an instrument for explaining and recording the circumstances involved with the loss, damage, or destruction of Air Force property. It supports the dropping of property from the records, resolves the question of responsibility, and fixes pecuniary liability. If an individual does not admit pecuniary liability or if the amount involved is over $250, a report of survey must be prepared.

Preparing the report of survey form is the first step. The individual who has custodial responsibility for the property starts the process. A provision has been made for others to perform this duty only when it is impractical for the individual to fill it out personally. AFM 177-111 and *Freight Loss and Damage Claims* (AFR 177-14) provide guidance and direction in the preparation of reports of survey.

As we previously stated, the report of survey is a means for explaining the loss, damage, or destruction of Government property and for securing relief from responsibility. For these reasons, responsible individuals should include every pertinent fact and circumstance surrounding the loss. Remember that the information presented on the report of survey is the basis for deciding whether an investigation is necessary. It is important that reports of survey be processed within 30 days of the discovery of the loss. The investigation must be made while the persons involved (including witnesses) are available and the facts are still fresh. After the report is complete, it goes to the base appointing authority for review and appropriate action.

If the report of survey is approved, the individual is relieved of the responsibility for the property and does not reimburse the Air Force for the cost of the item. However, if the reviewing authorities decide the individual was negligent, the Air Force must be reimbursed.



STATEMENT OF CHARGES FOR GOVERNMENT PROPERTY LOST, DAMAGED OR DESTROYED

MILITARY PAY ORDER NUMBER

DATE 30 Nov 76

CLASS OF PROPERTY AIR FORCE (SE)

ORGANIZATION 370th Bomb Sq (M)

FOR MONTH OF November

STOCK RECORD ACCOUNT OR OTHER PROPERTY RECORD OF ACCOUNTABLE OFFICER EAID No. 370391750000

STATION Kincheloe AFB, MI

STOCK NO.	ARTICLES	QUANTITIES 1	2	3	4	5	6	7	TOTAL ARTICLES	UNIT PRICE	TOTAL
7210-00-160-0375	Comforter, Bed		1		1				2	$10.40	$20.80
7210-00-221-0352	Blanket	1							1	8.05	8.05
7210-00-527-6089	Cover, Mattress	1		1	1				3	3.00	9.00
	*Depreciation computed at 25%										
										GRAND TOTAL	$37.85

CERTIFICATE OF RESPONSIBLE INDIVIDUALS

I certify that my signature hereon consititues:

a. An authorization to recover the amount of indebtness by payroll deduction.

b. An affirmation that the articles are not now in my possession.

c. An agreement to turn in to the appropriate supply officer all articles later recovered, it being understood that the United States Government retains title to the articles listed hereon.

COL NO.	NAME, GRADE AND SOCIAL SECURITY NUMBER	CAUSE FOR CHARGE	TOTAL CHARGE	SIGNATURE OF INDIVIDUAL & AMOUNT ACCEPTED: SIGNATURE	AMOUNT ACCEPTED
1	NAME Francis L. Fisher GRADE Sgt SSN 401-54-1095	Lost thru neglect	$8.29	Francis L Fisher	
2	NAME James A. Anketelle GRADE SSgt SSN 326-26-1728	Lost thru neglect	7.80	James A Anketelle	
3	NAME Richard G. Jannis GRADE Amn SSN 262-62-1348	Lost thru neglect	2.25	Richard G Jannis	
4	NAME Jack P. Delano GRADE Sgt SSN 248-61-7798	Destroyed thru carelessness	10.05	Jack P. Delano	
5	NAME GRADE SSN				
6	NAME GRADE SSN				
7	NAME GRADE SSN				
	GRAND TOTAL		28.39		

ORGANIZATION COMMANDER

The statements hereon are complete and correct, all damaged property has been disposed of in accordance with current directives and the charges have been computed in accordance with the provisions of AR 735-11 *(AFM 67-1 for USAF)*.

DATE 3 Dec 76

SIGNATURE Colbert B. Watkins
Colbert B. Watkins
Lt Col, USAF Commander

DISBURSING OFFICER OR PAYROLL CERTIFYING OFFICER

The charge set opposite the name of each person listed hereon has been entered on the appropriate pay record or payroll, or DD Form 139 has been prepared and forwarded for collection.

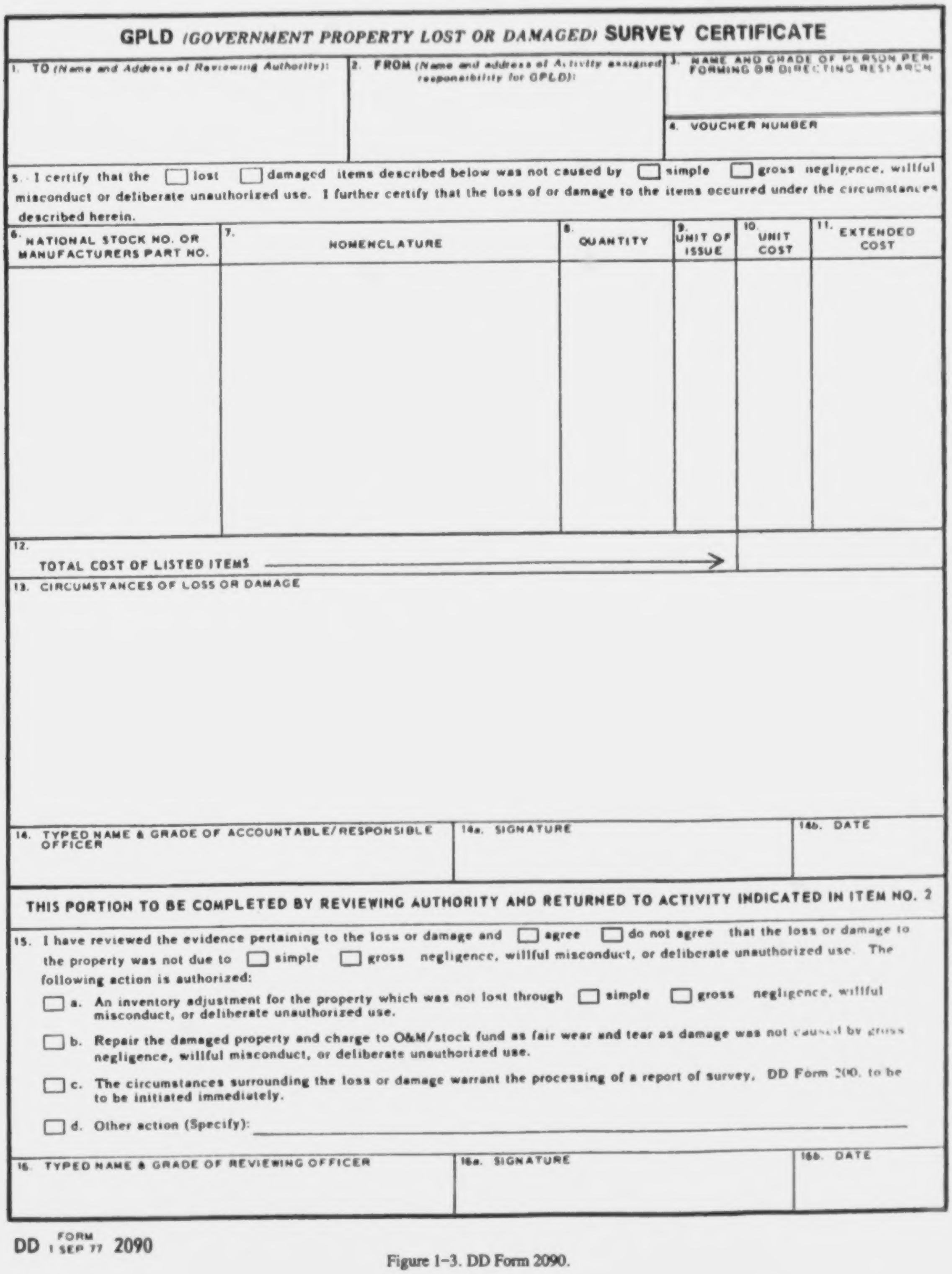
DATE 5 Dec 76

SIGNATURE Roy M. Meredith
Roy M. Meredith, 1Lt, USAF

PROPERTY VOUCHER NUMBER

DD FORM 1 MAR 76 362 REPLACES DD FORM 362, 1 SEP 69, WHICH MAY BE USED UNTIL EXHAUSTED.

Figure 1-2. DD Form 362.



GPLD *(GOVERNMENT PROPERTY LOST OR DAMAGED)* **SURVEY CERTIFICATE**

1. TO *(Name and Address of Reviewing Authority)*:

2. FROM *(Name and address of Activity assigned responsibility for GPLD)*:

3. NAME AND GRADE OF PERSON PERFORMING OR DIRECTING RESEARCH

4. VOUCHER NUMBER

5. I certify that the ☐ lost ☐ damaged items described below was not caused by ☐ simple ☐ gross negligence, willful misconduct or deliberate unauthorized use. I further certify that the loss of or damage to the items occurred under the circumstances described herein.

6. NATIONAL STOCK NO. OR MANUFACTURERS PART NO.	7. NOMENCLATURE	8. QUANTITY	9. UNIT OF ISSUE	10. UNIT COST	11. EXTENDED COST

12. TOTAL COST OF LISTED ITEMS →

13. CIRCUMSTANCES OF LOSS OR DAMAGE

14. TYPED NAME & GRADE OF ACCOUNTABLE/RESPONSIBLE OFFICER	14a. SIGNATURE	14b. DATE

THIS PORTION TO BE COMPLETED BY REVIEWING AUTHORITY AND RETURNED TO ACTIVITY INDICATED IN ITEM NO. 2

15. I have reviewed the evidence pertaining to the loss or damage and ☐ agree ☐ do not agree that the loss or damage to the property was not due to ☐ simple ☐ gross negligence, willful misconduct, or deliberate unauthorized use. The following action is authorized:

☐ a. An inventory adjustment for the property which was not lost through ☐ simple ☐ gross negligence, willful misconduct, or deliberate unauthorized use.

☐ b. Repair the damaged property and charge to O&M/stock fund as fair wear and tear as damage was not caused by gross negligence, willful misconduct, or deliberate unauthorized use.

☐ c. The circumstances surrounding the loss or damage warrant the processing of a report of survey, DD Form 200, to be to be initiated immediately.

☐ d. Other action (Specify): ____________________

16. TYPED NAME & GRADE OF REVIEWING OFFICER	16a. SIGNATURE	16b. DATE

DD FORM 1 SEP 77 2090

Figure 1-3. DD Form 2090.

Exercises (207):

1. State the purpose of a report of survey.

2. Who prepares a report of survey?

3. How soon after the discovery that equipment has been lost must a report of survey be filed?

1-2. Supply Authorization

The Air Force buys equipment, spare parts, and supplies to fill specific needs. The equipment authorized for your unit is based primarily on the unit mission. Other interrelated considerations include the number of people, number of aircraft, and climatic conditions.

For example, if performance of the mission requires special systems, or vehicles, then system or vehicle operators and maintenance personnel must be authorized. As more people are authorized, more clothes, tools, test equipment, space, and other things must be authorized to support the people.

208. State how and by whom quantities of equipment are determined and name the branch that resupplies bench stock and replacement items.

The equipment authorized your unit is based on USAF allowance documents. These documents give the average minimum quantities of each equipment item needed to accomplish the mission, but they do not necessarily show the exact quantities your unit is or will be authorized. The major commands and the Allowance and Authorization sections of Base Supply determine the exact quantities for each unit. They are influenced by such factors as (1) type of aircraft, (2) the number of aircraft to be maintained, (3) the size of the workload, (4) the type of maintenance to be performed, (5) the number of personnel, and (6) the climatic conditions.

Transactions with Base Supply. AFR 67-23, *Standard Base Supply Customer's Guide*, provides the information you need to do business with Base Supply. It also explains how to use the management products supplied by the standard base supply system (SBSS). The allowance and authorization section is responsible for the control of the base equipment. It also receives all requests for nonexpendable items listed on the table of allowance (TA) for your organization. Examples of these items are special tools, machines, and office equipment.

The base service store (BSS) issues and controls office and cleaning supplies and standard tools. Only those individuals authorized by your unit commander may shop in the base service store. The bench stock support unit resupplies authorized bench stocks with low cost, expendable items which, due to regular use, are put at the place where prevent unnecessary delays in maintenance.

Exercises (208):

1. The USAF allowance documents show the average minimum equipment amounts needed to accomplish the mission. Who determines the exact quantities to be issued?

2. What factors are used to arrive at a specific number of authorized pieces of equipment?

3. Why is a bench stock item stocked?

4. Which supply branch normally resupplies the bench stock items?

209. Name the index for tables of allowance and show how the index is categorized.

Tables of Allowance (TAs). AFR 0-10, *Management Control and Authorization Program of Allowance Source Codes for USAF Activities*, provides a consolidated list of all USAF Tables of Allowance. This AFR is the first document to consult when you want to locate a particular TA.

The TAs in AFR 0-10 are listed by categories. For example, TAs numbered 251 through 400 are categorized as Systems Support. This category includes TAs for air vehicles, such as helicopters, T-43 aircraft, and C-5A aircraft. TAs numbered 401 through 650 are for Facilities Support. This category includes allowances in such areas as General Purpose Tools, Printing Plant Auxiliary Equipment, and Food Services. TAs numbered 701 through 930 are for Mission Support and include such headings as Instrument, Automatic Pilot, and Navigation/Flight Control Systems Maintenance; Environmental Shop Intermediate Maintenance; and Aircraft Maintenance. Assume that you want the Systems Support TA for the C-5A aircraft. The index shows that it is TA 365. This TA lists equipment that applies exclusively to the C-5A aircraft.

Exercises (209):

1. Name the index for tables of allowance.

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TA 365 BASIC 15 APR 1974

TABLE OF CONTENTS

PART	SECT	SUB-SECT	END-ITEM	TITLE	PAGE NUMBER
A	A			PART A - FLIGHT LINE MAINTENANCE SECTION A - TECHNICAL EQUIPMENT	1
B	A			PART B - PERODIC DOCK MAINTENANCE SECTION A - TECHNICAL EQUIPMENT	4
C	A			PART C INTERMEDIATE MAINTENANCE SECTION A - AEROSPACE GROUND EQUIPMENT POOL	6
C	B			PART C SECTION B - AGE REPAIR SHOP	8
C	C			PART C SECTION C - AIRCRAFT REPAIR - AIRFRAME	10
C	D			PART C SECTION D - ENGINE SHOP	19
C	F			PART C SECTION F - HYDRAULIC SHOP	38
C	H			PART C SECTION H - MECHANICAL ACCESSORIES	53
C	J			PART C SECTION J - WELDING HEAT TREATING AND PLATING	59
C	K			PART C SECTION K - SHEET METAL AND PLASTIC	60
C	L			PART C SECTION L - FUEL AND OIL SYSTEMS	62
C	M			PART C SECTION M - MACHINE SHOP	64
C	P			PART C SECTION P - WHEEL AND TIRE	65
D	A			PART D - COMMUNICATIONS AND ELECTRONIC MAINT SECTION A - RADIO SHOP TEST EQUIPMENT	66
D	C			PART D SECTION C - RADAR SHOP TEST EQUIPMENT	74
D	E			PART D SECTION E - INSTRUMENTS	80
D	F			PART D SECTION F - AUTOMATIC FLIGHT CONTROL SYSTEM	86
D	G			PART D SECTION G - ELECTRIC SHOP	90
D	H			PART D SECTION H - COMPUTER	98
D	J			PART D SECTION J AVONICS AGE REPAIR SHOP	105

Figure 1-4. Table of contents, TA 365.

2. In what category in the TA index can you find TA 362, C-141A (MAC)?

3. What TA numbers are included in the Facilities Support category?

210. Cite the correct way to use TA 365 when you are determining given problems in systems support.

TA 365, C-5A aircraft (MAC). Figure 1-4 is a partial list of the Table of Contents for TA 365. As the figure shows, this TA contains four parts, A through D. Each part is divided into sections that identify the maintenance shops of the activity. Notice that Part A applies to flight line maintenance; Part B applies to periodic dock maintenance; Part C applies to intermediate maintenance; and Part D applies to communications and electronic maintenance. Each part is broken down into one or more sections. For example, Section E of Part D applies to instruments. The Table of Contents shows that the TA for instruments starts on page 80. Page 80 is shown in figure 1-5. Notice the title, Organization Item List, at the top of the page. (NOTE: Keep in mind that illustrations of TAs shown in this CDC are for training purposes only.) Because of the constant updating of TAs, the ones shown may not be correct.

Referring to figure 1-5, you can see that the TA lists the stock number and nomenclature of the line items of equipment. Also note the letter codes in the ACT column. The meaning of these codes is given in the instructions for the TA. For example, the A indicates an added item. The D indicates a deleted item. Now look at the letter codes A, B, C, and D appearing in columns on the right-hand portion of the page. These letter codes show the basis of issue of the equipment for the number of aircraft assigned. The meaning of these codes is also given in the instructions in the front of the TA. For example, the instructions for TA 365 state that column A listings give the authorized support for 4–6 aircraft, column B listings give the support for 14–18 aircraft, column C listings give the support for 19–24 aircraft, and column D listings give the support for 30–35 aircraft. The number immediately following the letter code is the number of line items of equipment authorized to support the number of aircraft indicated by the letter code. For example, "A 1" means that one line item of equipment is authorized for 4–6 aircraft. In most of the examples shown, the authorized quantities are the same for all four columns. Keep in mind that the values represented by the letter codes for basis of issue vary according to the particular TA. It is essential that you read the instructions in the front of the TA to determine the exact meaning of the codes.

We have discussed the Organization Item List section of TA 365 in some detail. TAs are also broken down into other sections. One section that you will probably find in any TA is the Allowance Summary. Figure 1-6 shows part of the Allowance Summary for TA 365. Notice that it lists the line items of the TA in stock number sequence. The maintenance shop that is authorized the item is identified in the SUB-DIV column. For example, stock number item 4920–081–0416, Test Harness Synchro Indicator, has a subdivision code DE. This code is derived from Part D, Section E. The Table of Contents tells you what shop this code represents. Referring to figure 1-4, you can see that Part D, Section E, is the instrument shop. The codes in the columns in the right-hand portion of figure 1-6 are a recapitulation of the Basis of Issue columns in the Organization Item List section of the TA.

Exercises (210):

1. Refer to figure 1-4. You want to determine the authorization for C–5A communications and electronic maintenance shops. What part of TA 365 provides this information?

2. You are having a problem determining the meaning of the basis of issue coding on a TA. Where can you find the answer to your problem?

3. You have an item of equipment and its stock number, but you are not sure that it is authorized. What portion of the TA should you consult to determine whether the item is authorized?

211. Cite specified procedures for using TAs in determining the mission support of a maintenance shop.

Earlier we mentioned that TAs for the mission support of a shop fall in the 701–930 category. The TA index (AFR 0–10) identifies TA 729 as Instrument, Automatic Pilot, and Navigation/Flight Control Systems Maintenance.

TA 729, Inst, A/P, and NAV/Flt Cont Sys Maint. Figure 1-7 shows a page from the Table of Contents for TA 729. Notice that this Table of Contents is structured in the same way as the Table of Contents for TA 365. (See fig. 1-4.) The Table of Contents for TA 729 lists end-items of equipment. You may be wondering about the term "end-items." An end-item is a finished item complete in itself, whether it is a simple piece of equipment or one made up of many parts. It is ready for its intended use. Supply uses "end-item" as a cataloging term. Notice in figure 1-7 that Part A of the Table of Contents pertains to instrument intermediate maintenance (tools and test equipment). Part B pertains to automatic flight control systems. Part B is further broken down into sections and subsections. Parts C and D (not shown) are also broken down in the same way.

Notice also that Part A of the TA for instrument intermediate maintenance starts on page 1. Part B of the TA for automatic flight control systems starts on page 12. Figure 1-8 contains excerpts of Part A, page 1, and Part B, page 12. In the Part A excerpt, the first item listed is a Machine-Drilling Upright Bench MTD. The quantity authorized for the instrument shop is one, given in column A under the basis of issue. However, this does not mean that you cannot ever have more than one drilling machine. If you need more than one to meet your maintenance requirements, you must justify the increase. If the need can be shown, an increase will be approved, but the TA will still show authorization for only one. The TA does not change just because your shop requires two drilling machines. A shop in Alaska may require one, and a shop in Texas three. It would be a never-ending process of changing a TA quantity authorization if, every time a shop supervisor requested more drilling machines, a quantity change was made in the TA.

The meaning of the ACT code in Part A Excerpt is given in the instructions for the TA. According to these instructions, the "A" means that this is an added item. The "C" indicates a change in the basis of issue. As we have said before, always read the instructions for the TA.

Now go back to the Table of Contents in figure 1-7. Here you will find that part B of the TA pertains to automatic flight control systems. As we mentioned earlier, this portion of the Table of Contents is broken down into sections and subsections. The letters representing the part, section, and subsection form a three-letter code. For example, part B, section A, and subsection H form the

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BASIC 15 APR  1974                              TA  365

                                           ORGANIZATIONAL ITEM LIST

                                  PART D
                                  SECTION E - INSTRUMENTS

STOCK NUMBER       NOTE CODES            EQ               ACT              BASIS OF ISSUE
       NOMENCLATURE                      CD

4110-879-5944
 REFRIGERATOR                                                           A 1     B 1     C 1     D 1

4920-NC776620PLH   CHANGE TO    4920-175-3324LH           D

* 4920-NC780292P                                        * A
                                                        * A             A 1     B 1     C 1     D 1

4920-081-0416                                             A
 TEST HARNESS SYNCHRO INDICATOR                           A             A 1     B 1     C 1     D 1
 PN-185191-999
      AGERD MR0312
                   CHANGE FROM  4920-081-0416LH

4920-081-0416LH    CHANGE TO    4920-081-0416             D

4920-081-0441                                             A
 ADAPTER TEST LIQUID QUANTITY SYSTEM                      A             A 1     B 1     C 1     D 2
 TEST SET PN-4S30035-101A
      AGERD MR0264
                   CHANGE FROM  4920-081-0441LH

4920-081-0441LH    CHANGE TO    4920-081-0441             D

4920-101-8924                                             A
 TEST PLUG PN-4S10022-101A                                A             A 1     B 2     C 2     D 3
      AGERD MR0444
                   CHANGE FROM  4920-101-8924LH

4920-101-8924LH    CHANGE TO    4920-101-8924             D

4920-103-6786                                             A
 ADAPTER TEST IWBS TRANSDUCER                             A             A 1     B 1     C 1     D 1
 PN-4S60031-101A
      AGERD MR1127
                   CHANGE FROM  4920-103-6786LH

4920-103-6786LH    CHANGE TO    4920-103-6786             D

4920-113-1776                                             A
 WIRING HARNESS BRANCHED                                  A             A 1     B 1     C 1     D 1
 PN-4S90776-101A
      AGERD LM0020
                   CHANGE FROM  4920-113-1776LH

4920-113-1776LH    CHANGE TO    4920-113-1776             D

4920-113-1777                                             A
 CABLE ASSEMBLY SPECIAL PURPOSE                           A             A 1     B 1     C 1     D 1
 ELECTRICAL PN-4S90853-101A
      AGERD LM0027
                   CHANGE FROM  4920-113-1777LH

4920-113-1777LH    CHANGE TO    4920-113-1777             D

4920-123-8798TP
 CABLE ASSY POWER ELECTRIC                                              A 1     B 1     C 1     D 1
 PN-4S60056-101A
      AGERD LM0211

4920-159-8949                                             A
 CABLE ASSEMBLY ELECTRICAL SPECIAL                        A             A 1     B 1     C 1     D 1
 PURPOSE BRANCHED PN-4560136-101A
      AGERD LM0740
                   CHANGE FROM  4920-159-8949LH

4920-159-8949LH    CHANGE TO    4920-159-8949             D

4920-175-3324                                             A
 ADAPTER TEST SET COMPUTER                                A             A 1     B 1     C 1     D 1
 PN-4S95047-101A
      AGERD LM0802
                   CHANGE FROM  4920-175-3324LH

4920-175-3324LH    CHANGE TO    4920-175-3324             D
                   CHANGE FROM  4920-NC776620PLH

                             **READ THE PREFACE AND NOTES**
```
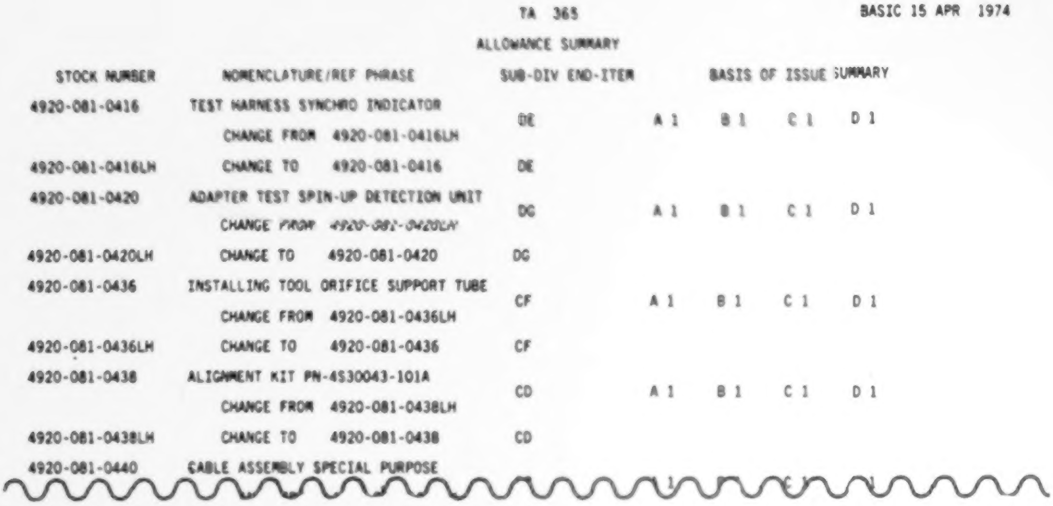

Figure 1–5. Organizational item list, TA 365.

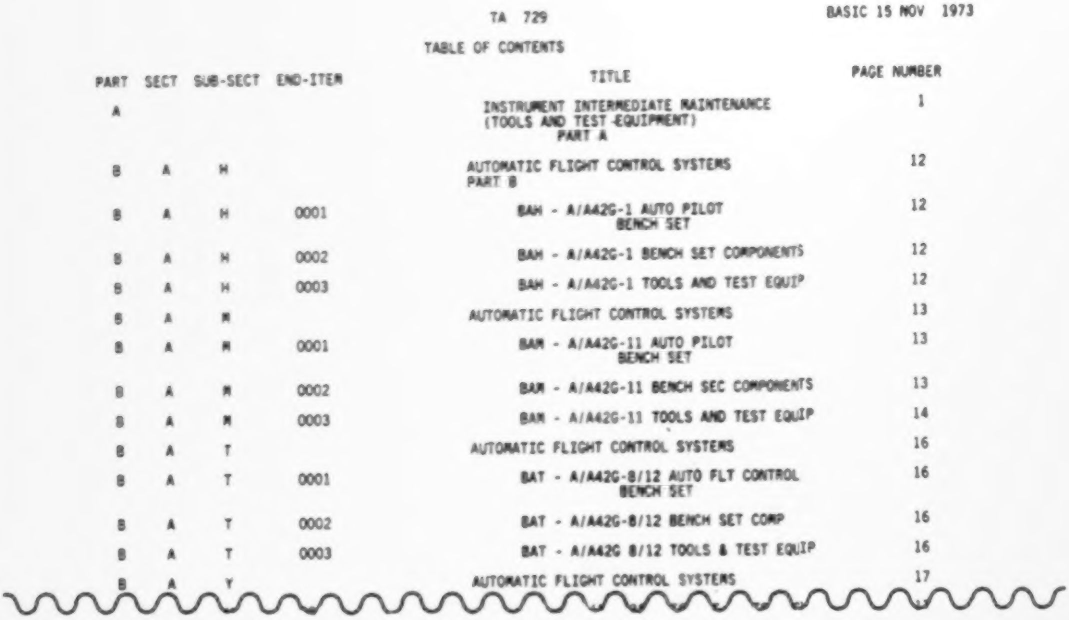


TA 365 BASIC 15 APR 1974

ALLOWANCE SUMMARY

STOCK NUMBER	NOMENCLATURE/REF PHRASE	SUB-DIV END-ITEM	BASIS OF ISSUE SUMMARY			
4920-081-0416	TEST HARNESS SYNCHRO INDICATOR CHANGE FROM 4920-081-0416LH	DE	A 1	B 1	C 1	D 1
4920-081-0416LH	CHANGE TO 4920-081-0416	DE				
4920-081-0420	ADAPTER TEST SPIN-UP DETECTION UNIT CHANGE FROM 4920-081-0420LH	DG	A 1	B 1	C 1	D 1
4920-081-0420LH	CHANGE TO 4920-081-0420	DG				
4920-081-0436	INSTALLING TOOL ORIFICE SUPPORT TUBE CHANGE FROM 4920-081-0436LH	CF	A 1	B 1	C 1	D 1
4920-081-0436LH	CHANGE TO 4920-081-0436	CF				
4920-081-0438	ALIGNMENT KIT PN-4S30043-101A CHANGE FROM 4920-081-0438LH	CD	A 1	B 1	C 1	D 1
4920-081-0438LH	CHANGE TO 4920-081-0438	CD				
4920-081-0440	CABLE ASSEMBLY SPECIAL PURPOSE		1		C 1	1

Figure 1–6. Allowance summary, TA 365.



TA 729 BASIC 15 NOV 1973

TABLE OF CONTENTS

PART	SECT	SUB-SECT	END-ITEM	TITLE	PAGE NUMBER
A				INSTRUMENT INTERMEDIATE MAINTENANCE (TOOLS AND TEST EQUIPMENT) PART A	1
B	A	H		AUTOMATIC FLIGHT CONTROL SYSTEMS PART B	12
B	A	H	0001	BAH - A/A42G-1 AUTO PILOT BENCH SET	12
B	A	H	0002	BAH - A/A42G-1 BENCH SET COMPONENTS	12
B	A	H	0003	BAH - A/A42G-1 TOOLS AND TEST EQUIP	12
B	A	M		AUTOMATIC FLIGHT CONTROL SYSTEMS	13
B	A	M	0001	BAM - A/A42G-11 AUTO PILOT BENCH SET	13
B	A	M	0002	BAM - A/A42G-11 BENCH SEC COMPONENTS	13
B	A	M	0003	BAM - A/A42G-11 TOOLS AND TEST EQUIP	14
B	A	T		AUTOMATIC FLIGHT CONTROL SYSTEMS	16
B	A	T	0001	BAT - A/A42G-8/12 AUTO FLT CONTROL BENCH SET	16
B	A	T	0002	BAT - A/A42G-8/12 BENCH SET COMP	16
B	A	T	0003	BAT - A/A42G 8/12 TOOLS & TEST EQUIP	16
B	A	Y		AUTOMATIC FLIGHT CONTROL SYSTEMS	17

Figure 1–7. Table of contents, TA 729.

three-letter coded BAH. You can see that these three-letter codes correspond to the code letters preceding the nomenclature of the particular item of equipment. According to the instructions for the TA, these code letters indicate that the item is used for the maintenance of the F-105 aircraft.

Now look at Part Excerpt B in figure 1-8. As previously mentioned, this excerpt shows a portion of the page 12 referred to in the Table of Contents. Notice that the nomenclature of the end items listed in Part B Excerpt are also identified with the three-letter code BAH. Also notice that this particular TA page shows two Basis of Issue columns, A and B. The instructions for the TA tell you that the column A and B codes pertain to parts B, C, and D of the TA and indicate the following: column A codes—authorization for organizational maintenance; column B codes—authorization for intermediate maintenance. Note that none of the line items listed in the excerpt are authorized for organizational maintenance.

There is one final word about TAs that we want to stress. Under certain conditions, you can find some equipment listed in several TAs, but you may use only one TA for authorization.

By now you probably realize that we would need almost endless pages of explanation to cover every aspect of the use of TAs. However, with practical application, more experience, and research, you will find that supply procedures are sound when they are followed carefully. Keep these facts in mind. Applying the information that has been presented in this section, you will have little difficulty in carrying out the shop functions related to insuring that adequate equipment is available.

Exercises (211):

1. What TA lists the tools and test equipment necessary for an instrument shop to perform intermediate maintenance?

2. Refer to figure 1-7. What do the several three-letter codes that precede the nomenclature refer to? Where can you obtain specific information about them?

3. Refer to Part B Excerpt of figure 1-8. The TA does not give the type of maintenance that this equipment supports. How can you determine the type of maintenance the equipment supports?

1-3. Identifying Supplies, Parts, and Equipment.

Okay, you understand your responsibilities for Government property and you know about tools and test equipment authorization documents, but how do you get the parts and supplies you need to do your job?

Have you ever ordered fishing gear, clothes, toys, or other things from a catalog? You copied down the item reference number and the name of the item and listed the quantity you wanted on the order blank. Then you sent your order in to a mail-order store, and the merchandise you ordered was shipped to you.

The Air Force supply systems works about the same way. You determine the need for an item, do some research to find the proper reference number for the item, and order it on the proper forms.

Every item in the Air Force must have a positive identification. For an item to be properly identified, it must have a national stock number, a correct name or noun, and a complete description. This data is needed not only for the preparation of issue and turn-in documents and property accountability records, but you must be able to tell someone exactly what you need so they can get if for you.

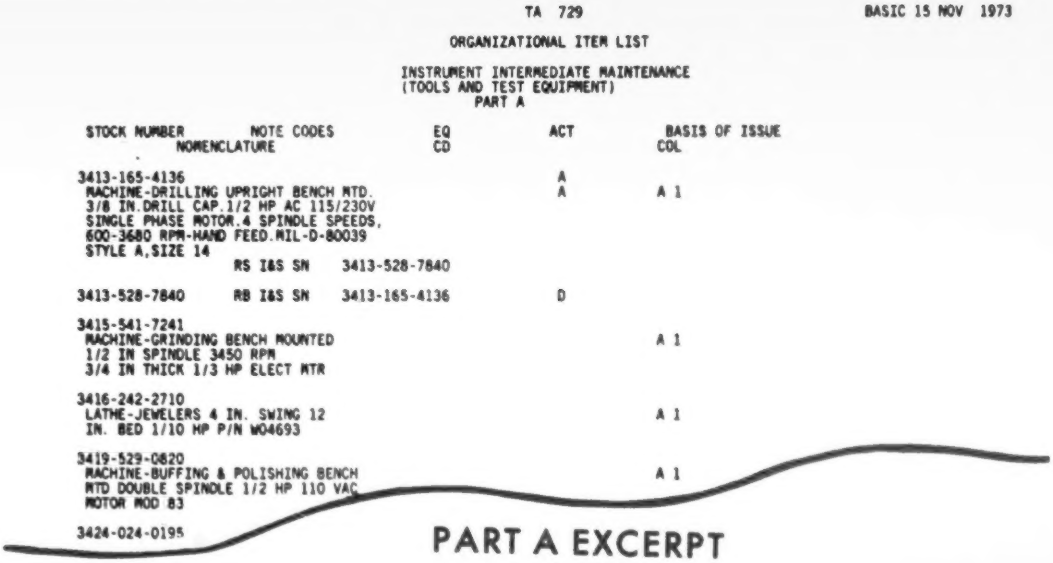
212. State the meaning of key aspects of the classification and identification system used for supplies, state the purposes of the NIIN and the manufacturer's code number, and list reference number examples.

Supply Classification and Identification System. In the day-to-day operation of a shop, numerous items are ordered from supply. The key to success in ordering supplies is proper identification. A verbal description of an item means little or nothing to supply. You must use the numbering system which was developed to identify items in the supply system. Each item within the supply system is assigned a national stock number (NSN).

National stock number. The national stock number is a 13-digit (all numerical) number. It is divided into two main parts: the Federal Supply Classification (FSC) code and the national item identification number (NIIN). The first four digits are the FSC. They are subdivided into two-digit units. The first two digits are the FSC group, grouping broadly related items. The second two digits of the FSC are the FSC class, grouping closely related items within the FSC group. Look at figure 1-9, specifically the digits 47 and 30.

The last nine digits are the national item identification number (NIIN) portion of the national stock number (NSN). They precisely identify the individual item and permanently differentiate it from all other items. The first two digits of the NIIN are the National Classification Bureau (NCB) code. This code identifies the country assigning the number. The remaining seven digits distinguish a specific item of supply within the Federal Cataloging System. Note that the NIIN is separated after the 00 digits and after its fifth digit. These separations help to prevent errors in transcribing and transmitting the number. The correct stock number must be placed on a requisition or supply document because the stock number is the key to the entire supply system of item identification. The entire process (supply, issue, storage, and accounting) breaks down and becomes confused when incorrect stock numbers are used.

Reference number. The reference number is used to identify an item of production or (by itself or in conjunction



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                                                  TA  729                         BASIC 15 NOV  1973

                                            ORGANIZATIONAL ITEM LIST

                                        INSTRUMENT INTERMEDIATE MAINTENANCE
                                        (TOOLS AND TEST EQUIPMENT)
                                                  PART A

 STOCK NUMBER        NOTE CODES              EQ              ACT              BASIS OF ISSUE
        NOMENCLATURE                         CD                              COL

3413-165-4136                                                 A
 MACHINE-DRILLING UPRIGHT BENCH MTD.                          A              A 1
 3/8 IN.DRILL CAP.1/2 HP AC 115/230V
 SINGLE PHASE MOTOR.4 SPINDLE SPEEDS,
 600-3680 RPM-HAND FEED.MIL-D-80039
 STYLE A,SIZE 14
                RS I&S SN    3413-528-7840

3413-528-7840   RB I&S SN    3413-165-4136                    D

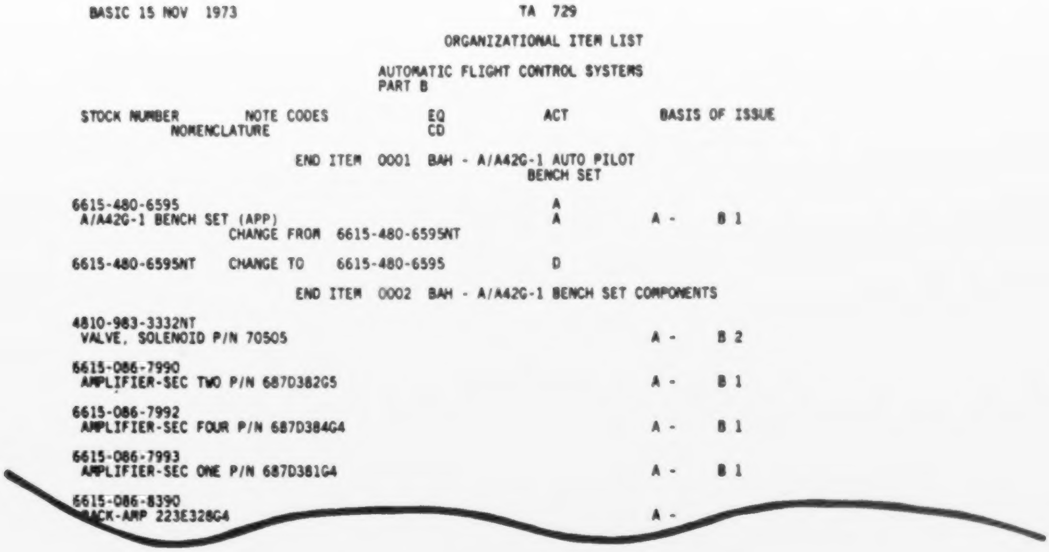
3415-541-7241
 MACHINE-GRINDING BENCH MOUNTED                                              A 1
 1/2 IN SPINDLE 3450 RPM
 3/4 IN THICK 1/3 HP ELECT MTR

3416-242-2710
 LATHE-JEWELERS 4 IN. SWING 12                                               A 1
 IN. BED 1/10 HP P/N W04693

3419-529-0820
 MACHINE-BUFFING & POLISHING BENCH                                           A 1
 MTD DOUBLE SPINDLE 1/2 HP 110 VAC
 MOTOR MOD 83

3424-024-0195
```

PART A EXCERPT



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 BASIC 15 NOV  1973                                TA  729

                                            ORGANIZATIONAL ITEM LIST

                                       AUTOMATIC FLIGHT CONTROL SYSTEMS
                                       PART B

 STOCK NUMBER        NOTE CODES              EQ              ACT              BASIS OF ISSUE
         NOMENCLATURE                        CD

                              END ITEM  0001  BAH - A/A42G-1 AUTO PILOT
                                                        BENCH SET

6615-480-6595                                                 A
 A/A42G-1 BENCH SET (APP)                                     A              A -     B 1
                    CHANGE FROM  6615-480-6595NT

6615-480-6595NT     CHANGE TO    6615-480-6595                D

                              END ITEM  0002  BAH - A/A42G-1 BENCH SET COMPONENTS

4810-983-3332NT
 VALVE, SOLENOID P/N 70505                                                   A -     B 2

6615-086-7990
 AMPLIFIER-SEC TWO P/N 687D382G5                                             A -     B 1

6615-086-7992
 AMPLIFIER-SEC FOUR P/N 687D384G4                                            A -     B 1

6615-086-7993
 AMPLIFIER-SEC ONE P/N 687D381G4                                             A -     B 1

6615-086-8390
  ACK-AMP 223E328G4                                                          A -
```

PART B EXCERPT

Figure 1–8. Excerpts from TA 729.

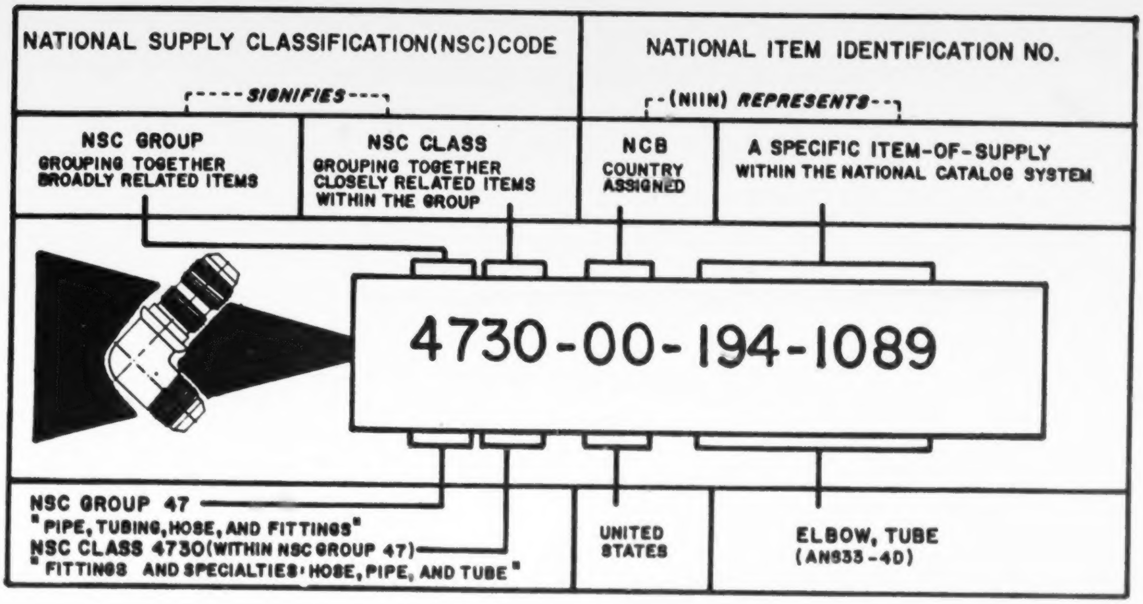

NATIONAL SUPPLY CLASSIFICATION(NSC)CODE
SIGNIFIES
NATIONAL ITEM IDENTIFICATION NO.
(NIIN) REPRESENTS
NSC GROUP
GROUPING TOGETHER BROADLY RELATED ITEMS
NSC CLASS
GROUPING TOGETHER CLOSELY RELATED ITEMS WITHIN THE GROUP
NCB
COUNTRY ASSIGNED
A SPECIFIC ITEM-OF-SUPPLY
WITHIN THE NATIONAL CATALOG SYSTEM
4730-00-194-1089
NSC GROUP 47
"PIPE, TUBING, HOSE, AND FITTINGS"
NSC CLASS 4730(WITHIN NSC GROUP 47)
"FITTINGS AND SPECIALTIES: HOSE, PIPE, AND TUBE"
UNITED STATES
ELBOW, TUBE
(AN833-4D)

Figure 1-9. National stock number

with other reference numbers) an item of supply. Reference numbers include manufacturer's part, drawing, model, type, and source controlling numbers; specification controlling numbers, and the manufacturer's trade name when the manufacturer identifies the item by trade name only; specifications or standard numbers; and specifications or standard part, drawing, or type numbers. These numbers can usually be converted to NSNs by using the master cross-reference lists, which we will cover later.

Manufacturer's code. The technical name for this code is the Federal Supply Code for Manufacturers (FSCM). It is a coding system of five-digit numbers assigned to manufacturers or to companies which have design control of items procurred by agencies of the Federal Government. A five-digit code is assigned to manufacturers so that data can be processed into the master reference files maintained by the Directorate of Item Identification, Defense Logistics Service Center (DLSC). The FSCM number is used in conjunction with the DLSC item number, symbol, or trade name. The FSCM number and the DLSC item number are used in the screening of item identifications against each other, primarily to prevent duplication.

Exercises (212):

1. State the meaning of the first four digits of the NSN.

2. State the purpose of the NIIN.

3. List three examples of reference numbers.

4. State the purpose of the manufacturer's code number.

213. Specify how to use supply catalogs and references which are on microfiche.

Now that you know what a national stock number, reference number, and manufacturer's code represent, you can use this information for identifying items in supply publications such as catalogs and cross-references. All standard supply publications are being converted to microfiche, so let's cover them next.

Microfiche. Microfiche, pronounced mike-ro-fish, are miniaturizations of publications. They are designed to speed up identification of parts in supply channels. Microfiche is a flat sheet of microfilm, approximately 4 by 6 inches, which contains data presented in a grid pattern. Figure 1-10 shows the format used for microfiche. The header contains normal size, readable, identification information which indicates the kind of information contained on the film. A special viewer is required for reading microfiche because the images are reduced 48 times and there may be 270 frames per microfiche sheet. Each frame can have at least 180 entries. Multiplying 180 entries by 270 frames, we come up with 48,600 entries on a sheet of film the size of your hand.

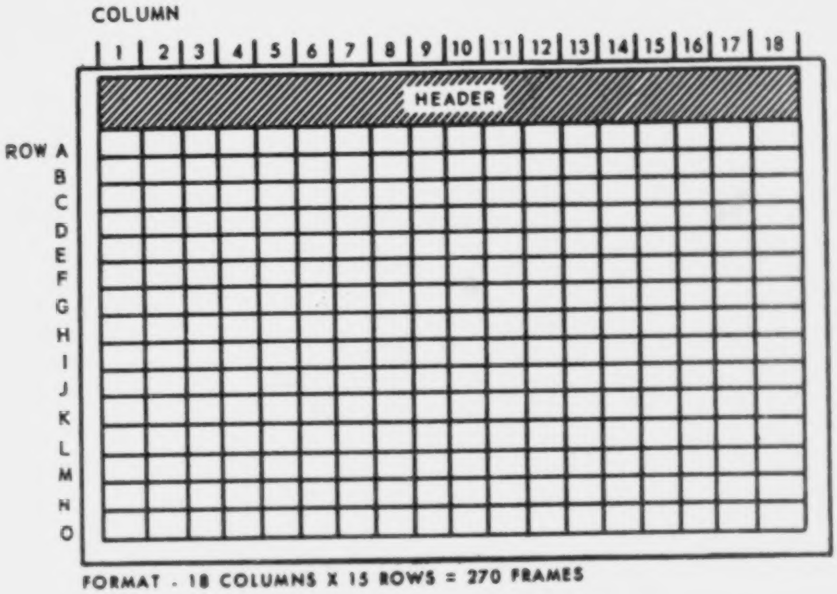


Figure 1-10. Microfiche sheet.

Viewer. The microfiche viewer is simple to operate. It has an on-off switch, a viewing screen, and a focusing knob. A selected sheet of microfiche is placed in the machine, and the images are projected on the screen where they can easily be read.

Supply lists, (such as the Tables of Allowances (TAs) previously discussed,) cross-reference lists (C–RLs), USAF Management Data lists (MLs), and USAF Identification Lists (ILs) provide various ways to locate items within the supply system.

C-RL-1, Master Cross-Reference List (fig. 1-11). This is a cross-reference, on microfiche, which converts manufacturer's identifying numbers, 1, to national stock numbers, 3. It also lists the manufacturer's code, 2. This index lists all approved manufacturer's part numbers in alphanumeric sequence. You may see identical part numbers listed many times, with each listing giving a different NSN. The only way you can know which stock number is for the part that you want is to know the manufacturer's code, which is given in the IPB that you used as your reference.

C-RL-2, Master Cross-Reference List. This index lists all NSNs in sequence. It is used to convert NSNs back to manufacturer's part numbers. It, too, lists the manufacturer's code.

Now that you know how to use the cross-reference lists, you may want to know how much a part costs, the unit of issue, the approved name, etc.

USAF management data list (ML-AF). The Management Data List (fig. 1-12) provides the minimum information necessary for ordering an item. It is frequently used to locate information for filling out requisition forms, turn-in slips, and other forms.

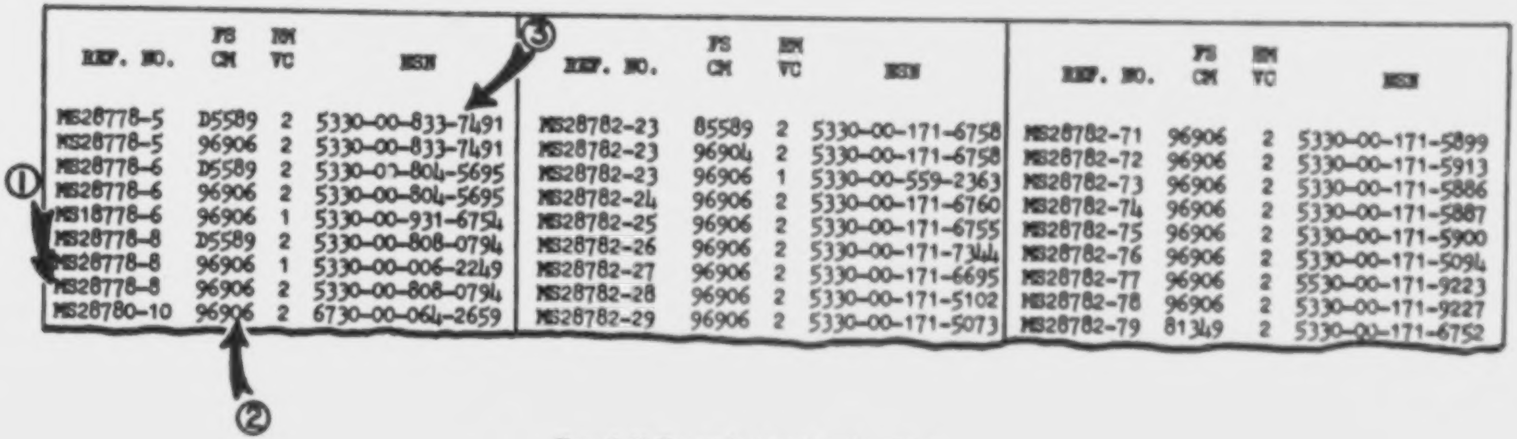
At first glance, it appears that the NSNs are not arranged in a logical order. Take another look. They are arranged in numerical sequence by the NIIN (last nine digits) of the national stock number. The FSC (first four digits) is disregarded for now. When you go down the list and find the NIIN you are looking for, be sure that you have the right FSC. Data in the ML includes:

- Issue and fund (money) control codes.
- Procurement and issue status codes.
- Expendability, repairability, recoverability codes (ERRC).
- Unit of issue codes (each, pound, gallon, sheet, etc.).
- Standard price.
- Source of supply.

USAF Identification List (IL-AF). The identification list identifies the item completely. Such data as material used, dimensions, etc., are included. It even has some illustrations.

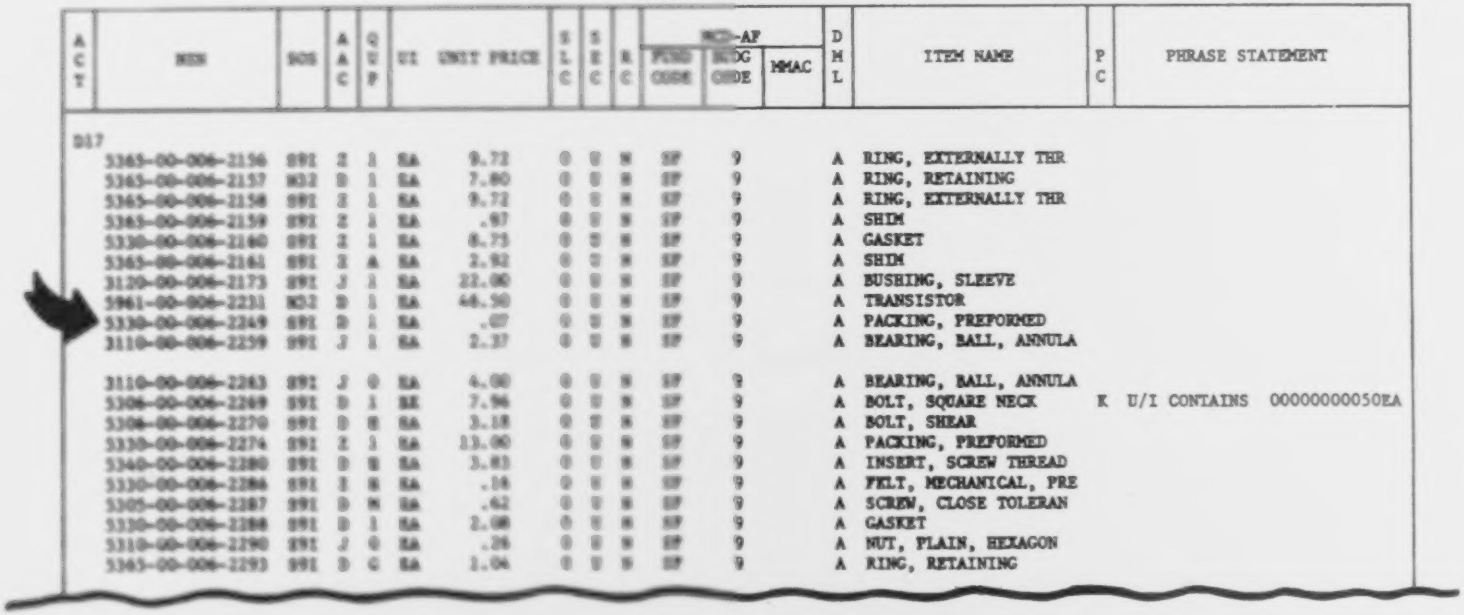
As you can see, there are three distinct steps that you should take when researching an item you intend to requisition. First, find the part number. It may be stamped on the item, or it may be indicated in the illustrated parts breakdown (IPB) of the TO. (If you have a stock number, you can cross-reference it to a part number by using the C–RL–2.) Second, find the stock number by cross–referencing it in the C–RL–1. Third, using the ML or IL, find the specific information you need.

We have mentioned but a few of the supply publications that you will use. Keep in mind that personnel in the research section of Base Supply are always willing to help you with any problems that you may have.



REF. NO.	FS CM	RM VC	NSN	REF. NO.	FS CM	RM VC	NSN	REF. NO.	FS CM	RM VC	NSN
MS28778-5	D5589	2	5330-00-833-7491	MS28782-23	85589	2	5330-00-171-6758	MS28782-71	96906	2	5330-00-171-5899
MS28778-5	96906	2	5330-00-833-7491	MS28782-23	96904	2	5330-00-171-6758	MS28782-72	96906	2	5330-00-171-5913
MS28778-6	D5589	2	5330-07-804-5695	MS28782-23	96906	1	5330-00-559-2363	MS28782-73	96906	2	5330-00-171-5886
MS28778-6	96906	2	5330-00-804-5695	MS28782-24	96906	2	5330-00-171-6760	MS28782-74	96906	2	5330-00-171-5887
MS18778-6	96906	1	5330-00-931-6754	MS28782-25	96906	2	5330-00-171-6755	MS28782-75	96906	2	5330-00-171-5900
MS28778-8	D5589	2	5330-00-808-0794	MS28782-26	96906	2	5330-00-171-7344	MS28782-76	96906	2	5330-00-171-5094
MS28778-8	96906	1	5330-00-006-2249	MS28782-27	96906	2	5330-00-171-6695	MS28782-77	96906	2	5530-00-171-9223
MS28778-8	96906	2	5330-00-808-0794	MS28782-28	96906	2	5330-00-171-5102	MS28782-78	96906	2	5330-00-171-9227
MS28780-10	96906	2	6730-00-064-2659	MS28782-29	96906	2	5330-00-171-5073	MS28782-79	81349	2	5330-00-171-6752

Figure 1-11. Part number to stock number listing.



ACT	NSN	SOS	AAC	QUP	UI	UNIT PRICE	SLC	SEC	RC	MCD-AF FUND CODE	MCD-AF BUDG CODE	MCD-AF MMAC	DML	ITEM NAME	PC	PHRASE STATEMENT
D17																
	5365-00-006-2136	S9I	Z	1	EA	9.72	0	U	N	8F	9		A	RING, EXTERNALLY THR		
	5365-00-006-2137	M02	D	1	EA	7.80	0	U	N	8F	9		A	RING, RETAINING		
	5365-00-006-2138	S9I	Z	1	EA	9.72	0	U	N	8F	9		A	RING, EXTERNALLY THR		
	5365-00-006-2159	S9I	Z	1	EA	.97	0	U	N	8F	9		A	SHIM		
	5330-00-006-2160	S9I	Z	1	EA	8.75	0	U	N	8F	9		A	GASKET		
	5365-00-006-2161	S9I	Z	A	EA	2.92	0	U	N	8F	9		A	SHIM		
	3120-00-006-2173	S9I	J	1	EA	22.00	0	U	N	8F	9		A	BUSHING, SLEEVE		
	5961-00-006-2231	M02	D	1	EA	46.50	0	U	N	8F	9		A	TRANSISTOR		
	5330-00-006-2249	S9I	D	1	EA	.07	0	U	N	8F	9		A	PACKING, PREFORMED		
	3110-00-006-2259	S9I	J	1	EA	2.37	0	U	N	8F	9		A	BEARING, BALL, ANNULA		
	3110-00-006-2263	S9I	J	0	EA	4.00	0	U	N	8F	9		A	BEARING, BALL, ANNULA		
	5306-00-006-2269	S9I	D	1	BX	7.96	0	U	N	8F	9		A	BOLT, SQUARE NECK	K	U/I CONTAINS 00000000050EA
	5306-00-006-2270	S9I	D	8	EA	3.18	0	U	N	8F	9		A	BOLT, SHEAR		
	5330-00-006-2274	S9I	Z	1	EA	13.00	0	U	N	8F	9		A	PACKING, PREFORMED		
	5340-00-006-2280	S9I	D	8	EA	3.83	0	U	N	8F	9		A	INSERT, SCREW THREAD		
	5330-00-006-2286	S9I	Z	8	EA	.18	0	U	N	8F	9		A	FELT, MECHANICAL, PRE		
	5305-00-006-2287	S9I	D	M	EA	.62	0	U	N	8F	9		A	SCREW, CLOSE TOLERAN		
	5330-00-006-2288	S9I	D	1	EA	2.08	0	U	N	8F	9		A	GASKET		
	5310-00-006-2290	S9I	J	0	EA	.26	0	U	N	8F	9		A	NUT, PLAIN, HEXAGON		
	5365-00-006-2293	S9I	D	C	EA	1.04	0	U	N	8F	9		A	RING, RETAINING		

Figure 1-12. USAF management data list.

Exercises (213):

1. State the purpose of microfiche.

2. State the function of the microfiche header.

3. Place the correct letter from column B in the blank space beside the appropriate function in column A.

Column A Function	*Column B* Publication
____ (1) Gives complete description of item requested.	a. C–RL–1.
____ (2) Gives part No. to stock number.	b. C–RL–2.
____ (3) Gives stock number to part number.	c. ML–AF.
____ (4) Gives unit price.	d. IL–AF.
____ (5) Is in NIIN sequence.	

4. Refer to figure 1-11. State the stock number of MS 28782–23 (manufacture 96906).

5. Refer to figure 1-12. State the price and unit of issue of stock number 5330–00–006–2288.

214. Define terms and state procedures used in the supply system.

Supply Terminology, Procedures, Forms, and Reports. The terminology, procedures, forms, and reports used in the supply system are a necessary part of aircraft maintenance. The standardized base supply system is designed around a computer system which furnishes meaningful management data to the customer (you) on a daily basis.

The UNIVAC 1050–II computer system keeps track of and updates information relating to all types of supply transactions. When you order an item, the request for the item is received by the demand processing unit of supply and fed (by a remote terminal) into the computer as an issue order. The computer searches its memory to see if the item is on hand and, if so, where. If the computer finds that the item is not on hand, it searches its memory to see if there are any substitutes or interchangeable items available.

If the requested item or a suitable substitute is available for issue, records are up-dated and an issue document is printed at the warehouse. The warehouseman takes the DD Form 1348–1, DOD Single Line Item Release/Receipt Document, gets the item off the shelf, and issues it to you. If the item is not available, the issue order is killed (cancelled), a request for the item is sent off-base to depot or another base, and a due-out (DUO) is established.

On a daily and weekly basis, a Priority Monitor Report is sent to each shop that has parts on order. A supervisor in the shop should review this report to verify that the priority of each request is still valid and that the part is still needed.

The computer is programmed to follow up on all outstanding requisitions. The item you have ordered is constantly being observed.

Thus far, we have discussed in-line issue procedures applicable to routine and priority requests, known as Prepost. Prepost is the act of updating computer-stored records before the physical movement of material. However, there are times when the computer is down (not operating). When this happens, supply is not able to input any transactions into the computer. This does not mean that you cannot receive your property. Supply personnel have various management reports and listings that provide information necessary to carry on without the help of the computer. The work will have to be manually prepared rather than computer processed. This means that it will be necessary to effect the movement of property first and put the information into the computer after the machine is "up" (in operation). This is called POST-POST, and all documents must be so annotated.

Exercises (214):

1. Which form will be used for issue from the warehouse?

2. What happens when an item is not in stock?

3. What is meant by POST-POST?

1-4. Obtaining Supplies/Parts

Supply customers are an integral part of the base supply system. To a large degree, your actions determine the ability of the base supply organization to support your demands. Therefore, designated supply representatives need to be thoroughly familiar with the contents of AFR 67–23, *Standard Base Supply Customer's Guide*. Good communications with Supply will contribute to a mutual understanding and resolution of problems that affect your ability to meet assigned missions.

When reparable parts are needed, you first check to see if the parts are located in the forward supply point. If the parts are expendable, you first check your bench stock. If the part(s) you need are not available at either location, then you order the part(s) from Base Supply.

215. State the purpose of supply points and bench stocks.

Supply Points. Supply points are established in coordination between the chief of supply and the deputy commander for maintenance, base civil engineer, or other appropriate organization manager. Items stocked in the supply point normally are assets that are peculiar to the needs of the supported activity and that have a high rate of usage. The purpose of the supply point is to make these assets immediately available to the using activity.

The supported activity must submit to the supplies management office a list of items to be placed in the supply point. The following information is required:

a. Stock number.
b. Part number.
c. Noun.
d. End item application (type aircraft, vehicle).
e. Whether functional check calibration is required before being stored in the supply point. A list of items stocked in the supply point is provided to the supporting materiel control and other activities as required.

All supply point issues are over the counter. Provide the following information at the time of issue:

- Stock number.
- Quantity required.
- Organization and shop codes.

Bench Stock. Bench stock consists of low-cost, expendable items which, due to repetitive consumption, are placed at the point of use before actual need. The most obvious advantage to this system is that the items are immediately available to the user. There are, however, certain disadvantages. From a customer's viewpoint, the most important of these is the fact that, with few exceptions, bench stock assets are funded items and must be paid for by your organization before actual use. Therefore, the organization commander must be aware of the dollar value of bench stock items to insure that adequate money is available to support requirements.

One shop bench stock per maintenance shop area is authorized. If two or more shops are in the same room or area, a single bench stock can handle the needs of both shops.

Most of the items in bench stock are expendable or nonrecoverable. Their per-unit value normally ranges from a fraction of a cent to $10. The primary purpose of working stock is to provide uninterrupted operation and to speed delivery of the items. Bench stock supplies are items that do not lend themselves to repair and are not authorized as repair cycle stock. When you set up your bench stock, do not establish more than a 30-day expected usage level, except for unit packages. A unit package (such as a box of screws) contains a number of items. Supply will not break a unit package and issues the entire package. Therefore, a unit package is issued for bench stock even if the 30-day expected use is less than the number of items in the package.

The establishment of a shop bench stock is a coordinated effort between maintenance and supply. You will find the information you need to establish a bench stock in AFM 66–11, *Maintenance Management*, and AFM 67–1, *USAF Supply Manual*. While you are preparing your bench stocklist, it is imperative that you work closely with your maintenance officer. Before you can make a list of your bench stock needs, you must determine the types and quantities of items to be stocked initially. To guide you, two types of lists are available: (1) the weapon system (type of aircraft) initial supply stocklist and (2) a stocklist from an organization with a like weapon system. If these aids are not available, the supervisor must base the list upon his experience in maintaining the weapon system.

Materiel Control and the bench stock branch of Base Supply review the list to decide if the items and amounts are justified. Be sure you can explain why you need each item, as well as its quantity. You will not be denied questioned items or quantities until the bench stock people of Base Supply have visited your shop and attempted to resolve the questions. If the question concerning the disputed item or quantity cannot be answered at this level, the problem will be resolved on the next higher level of supervision.

Supply delivers the bench stock items to your shop's bench stock and places the items in assigned bins. If it does not have an item in stock for the initial issue, the item is back-ordered and a due-out is established. Substituting items that are acceptable to maintenance is preferred to back ordering.

Each week, Supply checks your bench stock to be sure you have enough items on hand. If your bench stock is low in some items, supply personnel draw these items from Supply and place them in the assigned bins. One thing for you to keep in mind is that items may be added or deleted from your bench stock list at any time. Materiel Control investigates any large change in your requirements to see if the increase or decrease is permanent. If the change is permanent, it should be reflected in the supply stock level. If the change is temporary, it may require only a one-time adjustment in supply deliveries and no change in established levels.

Your maintenance activity (your shop) is solely responsible for providing adequate storage facilities for your bench stock. Your activity is also responsible for insuring the proper care and conservation of bench stock items, as specified in AFR 67–10. Normally, your inspection section, Quality Control, is responsible for determining the adequacy of your storage area.

Exercises (215):

1. Define the term "bench stock."

2. How often should the Base Supply monitor check your bench stock?

3. When you are developing a bench stock list, what usage level should you establish?

4. What two lists can you use as a guide for establishing a bench stock?

5. Identify the two activities that review your bench stock list to verify your need.

216. Identify specific organization bench stock listing entries and information from a selected bench stock label and determine whether the chosen items have cure dates or security codes.

Organization Bench Stock Listing. An organization bench stock listing is made in order to provide a complete listing of all items authorized in a bench stock. This listing is used by the bench stock support unit as well as by the individual maintenance shops. Bench stock listings differ due to the needs of each maintenance organization. Five different formats for this listing may be selected: a master bench stock listing in either (1) stock number or (2) part number sequence, and an organization bench stock listing in (3) stock number sequence, (4) part number sequence, or (5) item number sequence.

The organization bench stock listing is produced quarterly, following the bench stock review. However, it may be made on an as required basis at any time.

To help clarify the information on this listing, the following guideline is offered. Use figure 1-13 as you follow along with the explanations given here:

1. Card code	This column will have an A for add, D for recommended deletion, and a C for change. All this will be automatically done by the computer.
2. Stock number	National stock number is given here.
3. Part number	This is self-explanatory.
4. Organization code	A three-digit code that designates organizations appears here.
5. Shop code	Shop code locally. Two-digit alpha code.
6. Item number	This is the serial number assigned to the item. Notice that this listing is in bin sequence number.
7. System designator	Type of aircraft or support code appears here. Example: 17 for A7 aircraft and 01 for general support.
8. Nomenclature	The name of the item. This can be tailored to fit your needs, as long as you don't exceed 17 digits.
9. Budget code	This code will tell you whether the item is stock funded or not. Example: 1 = system support. 9 = general support.
10. Delivery distination	This is a three-digit code used by the requester to identify the area of delivery. As the requester, you can use any combination to establish a code. For example: 003 - Bldg P-3, Room E-102, etc.
11. Date of last demand (DOLD)	This is the date you last ordered this item.
12. Date of first demand (DOFD)	This is the date you first ordered this item.
13. Unit of issue	Give here the unit issued; for example: each (EA), gallon (GL), pound (LB).
14. Special level	Any item on a special level appears here.
15. Authorized level (Qty)	Put here the number of items authorized on bench stock.

①	②	③	④	⑤	⑥	⑦	⑧		⑨	⑩	⑪	⑫	⑬		⑭		⑮		⑯	⑰
															....QUANTITY...					
CC DI	STOCK NUMBER	PART/PIIN NR B/S LOCATION	ORG	SH	ITEM NR	SD	NOMENCLATURE	PRJ	B C	DEL DST	DOLD	DOFD	UI	S I	SL	COMP	AUTH	I X	UNIT PRICE	EXT AUTH $ VALUE
	9150 00223 4134		235	HK	0001	01	HYDRAULIC FL PETR		9	003	5177	4191	GL				20		$2.55	$51.50
	9150 00250 0926		235	HK	0002	01	PETROL TECHNICAL		9	003	5150	4133	LB				1		$ .64	$ .64
D	9505 00592 4690		235	HK	0003	01	WIRE STEEL CARBON		9	003	5092	4191	LB				4		$1.36	$5.44
C	4730 00842 2202		235	HK	0004	01	ADAPTER MS245087D		9	003	5177	5010	EA				42		$ .89	$37.38
	5330 00579 8156		235	HK	0005	01	PACKING PREF MS2B		9	003	5150	4191	EA				15		$ .03	$ .45
C	5330 00579 7916		235	HK	0006	01	PACKING PREF AN62		9	003	5177	4191	EA				49		$ .03	$ 1.47
C	5330 00936 0317		235	HK	0007	01	GASKET MS35803-11		9	003	5177	4191	EA				33		$ .05	$ 1.65
C	5330 00914 4093		235	HK	0008	01	GASKETPN AN6246/1		9	003	5171	4191	EA				50		$ .10	$ 5.00
C	5330 00171 8068		235	HK	0009	01	PACKING ANG227815		9	003	5177	4191	EA				28		$ .02	$ .56
	1650 00056 6125		235	HK	0010	01	PARTS KIT CYLINDE		1	003	5171	4191	EA	1	80	22	80		$2.37	$189.60

	BC 1		BC 9		BC OTHER		OVERALL	
	L/I	AUTH VALUE	L/I	AUTH VALUE	L/I	AUTH VALUE	L/I	AUTH VALUE
THIS SHOP	1	$189.60	9	$103.59	0	$.00	10	$293.19
THIS ORG	1	$189.60	9	$103.59	0	$.00	10	$293.19

Figure 1-13. Bench stock listing.

16. Unit Price	The price of each item on bench stock is entered here.
17. Total Price	The price X number of items you ordered goes here.

With the explanations, you should now be able to read this listing without much trouble. We don't want you, the average mechanic, to know everything about it, but you should be able to read it. Who knows, you might be placed in charge of the bench stock in your shop!

Bench Stock Label. The bench stock label which is placed on each bin of your bench stock contains quite a bit of information. But have you ever really looked close enough to realize this? If not, review what we have just explained, since each part of the label has been covered as we talked about the bench stock listing except for the shelf-life and the security codes, which we will discuss next.

Shelf-life code. This code is used to indicate the number of months after the date of manufacture that an item can be used. The date of manufacture may be found on the item package. AFM 67–1 states that some means of identifying cure-dated items must exist. In the example given in figure 1-14, we have shown two means of identifying whether or not an item is cure dated. Notice the items with an asterisk. First, we have placed a red stripe on the bench stock label. (This is a local policy and may not be used in all organizations.) This will tell you at a glance whether or not an item is cure dated. Secondly, the bench stock label has a code (5). Look now at Table 1-1. If the code is 5, you can see that it has a shelf life of 60 months, or 5 years. Remember that each item could have a different cure-date expiration, however.

Each time an item is taken from a bin, check to see whether or not the shelf life has expired. Check it against the shelf-life codes found in AFM 67–1. Also, at least quarterly, review items stored in bins with shelf-information codes to see whether or not the shelf life has expired. If you find an item with an expired shelf life, you should remove it or have it removed from the bin, and bring the matter to the attention of the bench stock support section. Note that, in some instances, the shelf life can be extended under the authority of TO 00–20–1.

Security code. The security code is used to indicate whether a particular item is a controlled item or not. For an example, if you have flashlight batteries on bench stock, you would not want them sitting in an open bin. Why? Because this practice would allow anybody to come in and take the batteries for private use. Instead, they should be placed in a controlled area, where they can be locked up. So, if you have a code J, this means a controlled item; if it is coded U, it would not be controlled. Notice in figure 1-14 that the packing is coded U.

Table 1-1, SHELF-LIFE-CODES

A	1	Month	S	18	Months
B	2	Months	T	21	Months
C	3	Months	2	24	Months
D	4	Months	U	18	Months
E	5	Months	V	30	Months
F	6	Months	W	33	Months
G	7	Months	3	36	Months
H	8	Months	X	42	Months
J	9	Months	4	48	Months
K	10	Months	5	60	Months
L	11	Months	&	65	Months
1	12	Months	6	72	Months
M	13	Months	7	84	Months
N	14	Months	8	96	Months
P	15	Months	9	108	Months
Q	16	Months	Z	120	Months
R	17	Months	Y	54	Months

NOTE: Shelf Life Code indicates numbers of months item may be used after date of manufacture. Date of manufacture may be found on the item package.

Exercises (216):

1. What does card code D on a bench stock listing mean?

2. What is the item number on a bench stock listing?

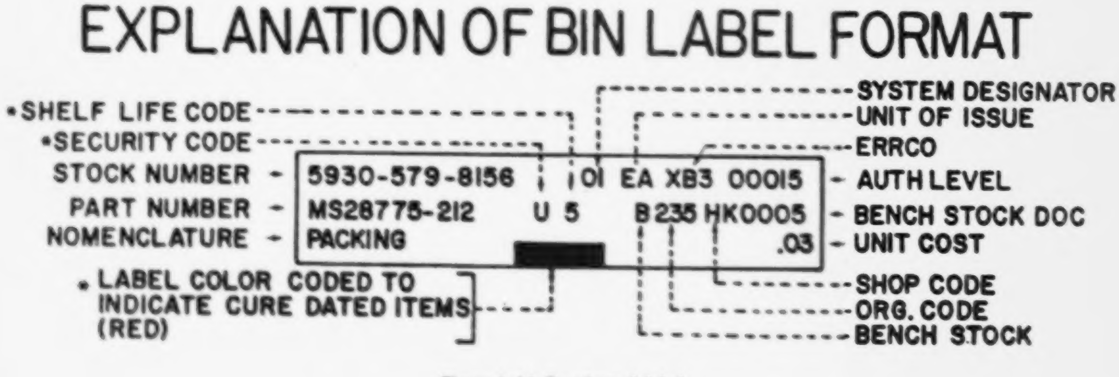
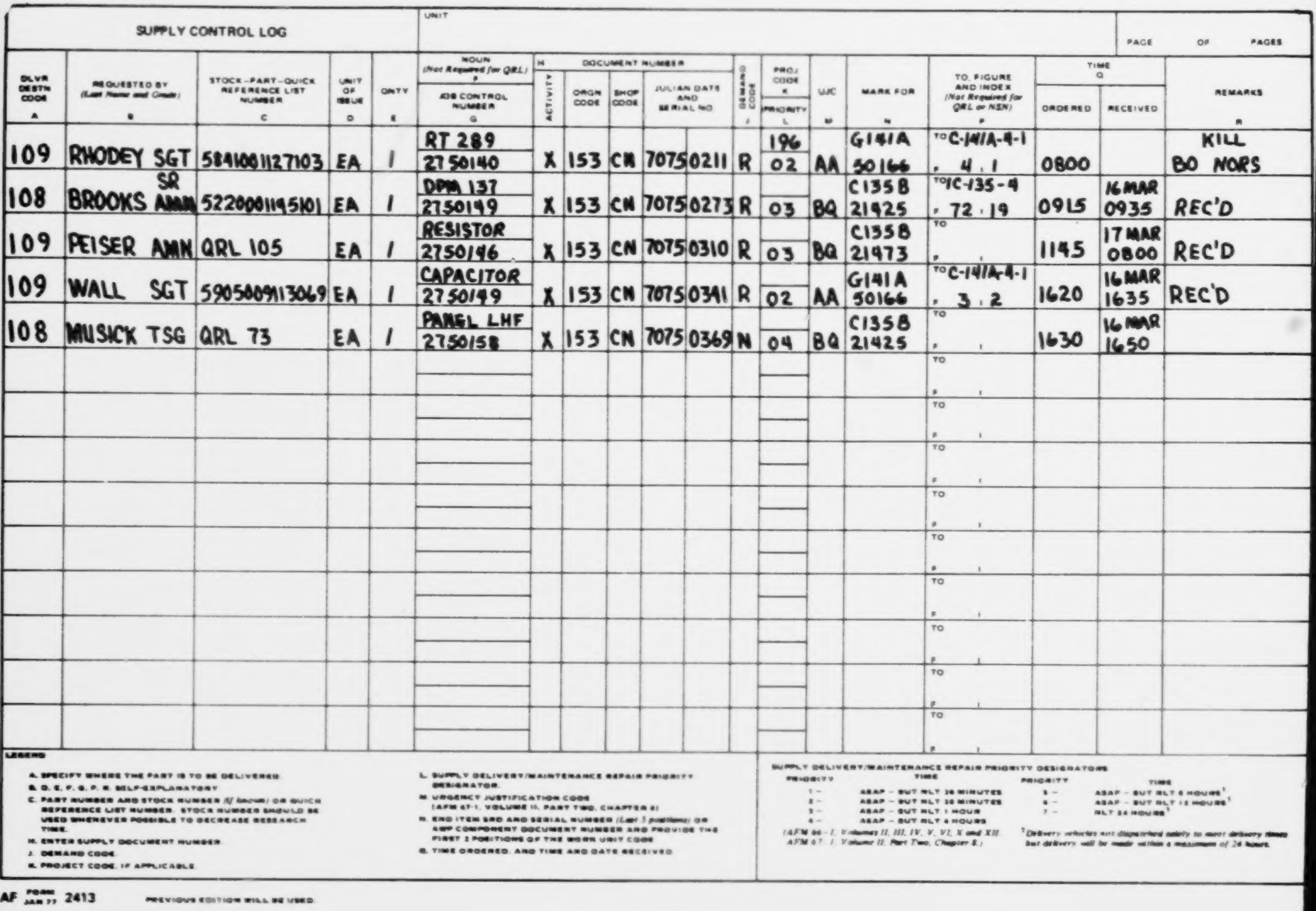


Figure 1–14. Bench stock label.



SUPPLY CONTROL LOG

UNIT

PAGE OF PAGES

DLVR DESTN CODE A	REQUESTED BY (Last Name and Grade) B	STOCK-PART-QUICK REFERENCE LIST NUMBER C	UNIT OF ISSUE D	QNTY E	NOUN (Not Required for QRL) F JOB CONTROL NUMBER G	H DOCUMENT NUMBER: ACTIVITY	ORGN CODE	SHOP CODE	JULIAN DATE AND SERIAL NO	DEMAND CODE J	PROJ CODE K PRIORITY L	UJC M	MARK FOR N	TO, FIGURE AND INDEX (Not Required for QRL or NSN) P	TIME Q: ORDERED	TIME Q: RECEIVED	REMARKS R
109	RHODEY SGT	5841001127103	EA	1	RT 289 2750140	X	153	CN	7075 0211	R	196 02	AA	G141A 50166	TO C-141A-4-1 F 4 . 1	0800		KILL BO NORS
108	BROOKS SR AMN	5220001145101	EA	1	DPM 137 2750149	X	153	CN	7075 0273	R	03	BQ	C135B 21425	TO 1C-135-4 F 72 . 19	0915	16 MAR 0935	REC'D
109	PEISER AMN	QRL 105	EA	1	RESISTOR 2750146	X	153	CN	7075 0310	R	03	BQ	C135B 21473	TO F ,	1145	17 MAR 0800	REC'D
109	WALL SGT	5905009113069	EA	1	CAPACITOR 2750149	X	153	CN	7075 0341	R	02	AA	G141A 50166	TO C-141A-4-1 F 3 . 2	1620	16 MAR 1635	REC'D
108	MUSICK TSG	QRL 73	EA	1	PANEL LHF 2750158	X	153	CN	7075 0369	N	04	BQ	C135B 21425	TO F ,	1630	16 MAR 1650	
														TO F ,			
														TO F ,			
														TO F ,			
														TO F ,			
														TO F ,			
														TO F ,			
														TO F ,			
														TO F ,			
														TO F ,			

LEGEND

A. SPECIFY WHERE THE PART IS TO BE DELIVERED.
B, D, E, F, G, P, R, SELF-EXPLANATORY
C. PART NUMBER AND STOCK NUMBER *(If known)* OR QUICK REFERENCE LIST NUMBER. STOCK NUMBER SHOULD BE USED WHENEVER POSSIBLE TO DECREASE RESEARCH TIME.
H. ENTER SUPPLY DOCUMENT NUMBER.
J. DEMAND CODE.
K. PROJECT CODE, IF APPLICABLE.
L. SUPPLY DELIVERY/MAINTENANCE REPAIR PRIORITY DESIGNATOR.
M. URGENCY JUSTIFICATION CODE (AFM 67-1, VOLUME II, PART TWO, CHAPTER 8)
N. END ITEM SRD AND SERIAL NUMBER *(Last 5 positions)* OR AWP COMPONENT DOCUMENT NUMBER AND PROVIDE THE FIRST 2 POSITIONS OF THE WORK UNIT CODE.
Q. TIME ORDERED, AND TIME AND DATE RECEIVED.

SUPPLY DELIVERY/MAINTENANCE REPAIR PRIORITY DESIGNATORS

PRIORITY	TIME	PRIORITY	TIME
1 –	ASAP – BUT NLT 30 MINUTES	5 –	ASAP – BUT NLT 6 HOURS[1]
2 –	ASAP – BUT NLT 30 MINUTES	6 –	ASAP – BUT NLT 12 HOURS[1]
3 –	ASAP – BUT NLT 1 HOUR	7 –	NLT 24 HOURS[1]
4 –	ASAP – BUT NLT 4 HOURS		

(AFM 66-1, Volumes II, III, IV, V, VI, X and XII. AFM 67-1, Volume II, Part Two, Chapter 8.)

[1] *Delivery vehicles not dispatched solely to meet delivery times but delivery will be made within a maximum of 24 hours.*

AF FORM JAN 77 2413 PREVIOUS EDITION WILL BE USED.

Figure 1-15. AF Form 2413.

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3. What does the shelf-life code on a bench stock label indicate?

4. How frequently should you inspect items on bench stock for expired shelf life?

5. Items on bench stock which may be preferred for personal use should have what security code on the label?

6. Using figure 1-13, identify the entries for each of the following items on Unit 9505 00592 4690.

   a. In this item to be added, deleted, or changed?

   b. The system designator is____________.

   c. The code that designates the organization is ____________.

   d. The unit of issue for this item is ____________.

   e. The shop is authorized ____________.

217. State the purpose of AF Form 2413, Supply Control Log, and give the meaning of selected entries on this form.

AF Form 2413, Supply Control Log. AF Form 2413, Supply Control Log, is a running account of all parts and supplies that have been ordered by your section. If properly maintained, it shows the status of all parts, whether they have been received, are on back order, or have been cancelled.

While following the explanation of the columns on the AF Form 2413, refer to figure 1-15. The top line is self-explanatory.

Column A, DLVR DESTN Code. Where part is to be delivered (quite often the building number is used).

Column B, Requested by. Self-explanatory.

Column C, Stock-Part-Quick Reference List Number. Stock and part number is self-explanatory. The basic purpose of a quick-reference list (QRL) is to provide maintenance personnel with a speedy identification and communication capability for placing a demand on Supply. Additonally, the listings aid Supply by eliminating repetitive research. When a base elects to use the QRL, maintenance supply liaison (MSL) will coordinate with Supply for the initial selection of QRL items by the use of Supply computer programs to identify high usage items. This coordination may include the requirement for Supply to assume responsibility for revisions and final publishing of quick reference lists. Final selection of items on the QRL will be made by Maintenance Supply Liaison.

Column D, Unit of Issue. Self-explanatory.

Column E, QNTY. Self-explanatory.

Column F, Noun. Self-explanatory.

Column G, Job Control Number. Job control number is same one that is on your AFTO Form 349 or AFTO Form 350.

Column H, Document Number. Most of the transactions you process with Base Supply are assigned an organizational document number composed of 14 alpha and numeric characters. It is a control or reference number that is used to identify a specific transaction. For example: R622HS–61240019.

R = activity code (1 alpha—1st position of document number).
622 = organization code (3 numeric—2d through 4th positions).
HS = shop code (2 alpha—5th and 6th positions).
6124 = Julian date (4 numeric—7th through 10th positions).
0019 = Serial number (4 numeric—11th through 14th positions).

This code identifies the method or location used by an organization in processing an issue or turn-in request to Base Supply. In some cases, it further identifies the type of item; for example: bench stock, war reserve materiel, etc. The codes that you normally use as a customer of Base Supply, or that appear in management products received from Base Supply, are listed below:

Code	Description
B	Bench stock (bench stock issues/turn-ins).
C	Contract maintenance/in-house repair/UR exhibits.
E	Equipment management (EAID issues/turn-ins).
J	Used by organizations on DO NOT POST actions, such as the turn-in of work order residue to DPDO. These transactions are not processed through Base Supply or the supply computer.
L	Bulk issue (base service store and individual equipment).
M	Mission support kit (issues/turn-ins).

Code	*Description*
P	Non-EAID equipment (issues/turn-ins of equipment items that are not accounted for on authorized/in-use detail records. Examples are transactions on aircraft inventory items; Civil Engineer real property installed equipment; and personal clothing and equipment items).
R	Routine issues/turn-ins.
S	Supply point (identifies a transaction related to operation of a supply point, including across the counter issues, turn-ins, actions between the supply point and the main base account).
U	War readiness spares kit (issues/turn-ins).
X	Expedite (issues/turn-ins).

The organization code is used to specifically identify your unit or subordinate activities. These codes are assigned by Base Supply in specific series for various types of activities, as directed by AFM 67–1, *USAF Supply Manual*. These same codes also are used by the base comptroller to maintain dollar data on the supplies and equipment drawn from or turned in to Base Supply.

The shop code further identifies the shop or office within your organization. AFM 67–1 suggests standard codes for certain functions; however, they are not mandatory except for Civil Engineer (CE) shops. CE shops must use stated codes. Shop codes must not be duplicated within the same organization or used by functions other than those to which assigned.

The Julian date is the standard Julian date; for example, 8124 is 4 May 1978. It indicates the date the document serial number was assigned.

Serial number numbers are assigned beginning with 0001 daily for each activity code. They are manually assigned, normally by Base Supply. A different numbering system is used for bench stock, supply point, authorized/ in-use equipment, and war reserve materiel items.

Column J, Demand Code. "R" for recurring or "N" for nonrecurring type items.

Column K, PROJ Code. This block is seldom used, but use the project code, if applicable.

Column L, Priority. This is the delivery priority and you can find the legend for this in the lower right-hand block of AF Form 2413 (fig. 1-15).

Column M, UJC. Urgency justification code (UJC) is a two-character code used to indicate urgency of need.

Column N, Mark For. The aircraft item is ordered against an AWP (awaiting parts) document number and the first two positions of the work unit code.

Column P, To, Figure and Index. These are from the IPB (illustrated parts breakdown) TO.

Column Q, Time. *Ordered* is time only and *Received* is both time and date.

Column R, Remarks. This block is for remarks, such as back ordered, request killed, request cancelled, etc.

Exercises (217):

1. State the purpose of the AF Form 2413.

2. What is a QRL? What is its purpose?

3. What are the five parts of the document number?

4. What is the purpose of the activity code?

5. What are the meanings of activity codes "R" and "X"?

6. Where would you get the information for column P of AF Form 2413?

218. Interpret entries required on the AF Form 2005, Issue/Turn-in Request.

AF Form 2005, Issue/Turn-in Request. The following information is required when submitting an AF Form 2005, Issue/Turn-in Request. (See fig. 1-16.) We will cover only the blocks you use.

TRIC, Transaction identification code. This code identifies the type of transaction you are conducting with supply. ISU is the code for issue and TIN for turn-in.

DEL DEST. The code you put in these three blocks tells supply where you want the item delivered to. It is a locally assigned code.

Block A. For issue request, put your name, the date and time in this block.

Stock number. The national stock number (NSN) goes here. If no NSN is available, leave blank.

Unit of issue. Self-explanatory.

Quantity. Self-explanatory.

Document number. Review the last objective if you do not understand the entries in this block.

Block D, Part number/MFGR code or name/remarks. In this block, enter the manufacturer's part number of the item. Also, enter the manufacturer's code or name and any remarks you feel are necessary to help supply personnel identify the item.

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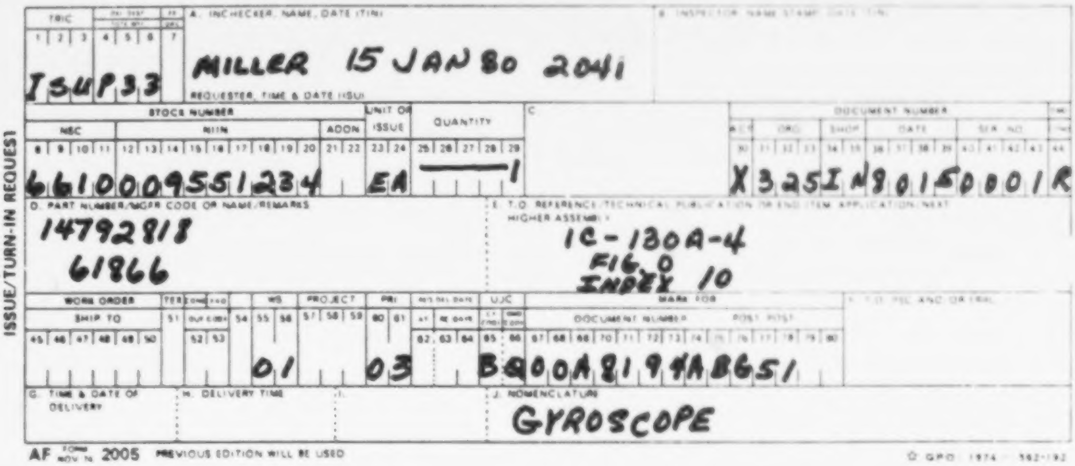

ISSUE/TURN-IN REQUEST

TRIC: ISUP33

A. INCHECKER, NAME, DATE (TIN)

MILLER 15 JAN 80 2041

REQUESTER, TIME & DATE (ISU)

B. INSPECTOR NAME STAMP DATE (TIN)

STOCK NUMBER (FSC, NIIN, ADDN): 6610009551234

UNIT OF ISSUE: EA

QUANTITY: 1

C.

DOCUMENT NUMBER: X325IN80150001R

D. PART NUMBER/MGFR CODE OR NAME/REMARKS: 14792818 61866

E. T.O. REFERENCE/TECHNICAL PUBLICATION OR END ITEM APPLICATION/NEXT HIGHER ASSEMBLY: 1C-130A-4 FIG. 0 INDEX 10

WORK ORDER / SHIP TO:

WS: 01

PROJECT:

PRI: 03

UJC / MARK FOR: BQ00A8194AB651

G. TIME & DATE OF DELIVERY:

H. DELIVERY TIME:

I.

J. NOMENCLATURE: GYROSCOPE

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GPO : 1974 — 562-192

Figure 1-16. AF Form 2005.

Block E, TO Reference/Technical publication or end-item application/next higher assembly." Give TO number, figure number, and index number if possible. If you do not have a TO reference, tell Supply what technical publication you used to identify the needed part. If unable to do so, tell them what the part is to be used on or what it is a part of.

WS. A work stoppage code goes here. Normally it will be 01, which means that the job cannot be completed until the part is received.

Project. Enter the 3-digit special project code if there is one.

Pri. Delivery priority requested.

UJC. Urgency justification code.

Mark For. The aircraft or equipment identification number plus the Standard Reporting Designator and the first two digits of the work unit code or the AWP (awaiting parts) document number of the part for which the item is needed.

Block J, Nomenclature. Enter the name of the item requested or being turned in.

Exercises (218):

1. What does the TRIC code on an AF Form 2005 identify?

2. What does work stoppage code 01 indicate?

219. State the procedure for ordering supplies/parts through the Demand Processing Section of Base Supply.

Supply Request Procedures. Demands will normally be made by telephone or radio for supply delivery priorities 1 through 4. When the volume of issue request would restrict call-ins to Demand Processing, or when workload dictates, AF Forms 2005 may be prepared and hand-carried to Supply. Demands for items stored in the supply points may be placed over the counter or through Demand Processing. Where radio communications are available to Demand Processing, radio call-in should be used.

The requester will complete AF Form 2413 (fig. 1-15) and provide the information from Columns A through P (with a few exceptions) in sequence for demand call-ins. The following are the exceptions:

Column B. Give telephone number in addition to name and grade.

Column G. Not applicable for call-ins.

Column H. The document number's Julian date is already known by Supply, and Supply will give you the serial number.

To complete the call-in entries, enter the document number provided by Supply and the time ordered.

The Air Force 2413 will be retained by the requesting organization or shop for verification of the daily document register (D04). The organizational maintenance acitivity will verify only those issue requests created for their organization and the shop codes on the daily document register.

Routine parts requests for non-NSN items will be delivered to demand processing accompanied by a DD Form 1348-6, Non-NSN Requisition (Manual). These forms will be prepared as outlined in AFM 67-1, Volume II, Part Two, Chapter 22, by the requester with assistance from Maintenance Supply liaison. When parts request are submitted by voice communications (urgency of need requirements "A" and "B") to Demand Processing, assistance will be provided by the requester to Demand Processing, Stock Control, or the Research Section in preparation of the DD Form 1348-6, as required.

Exercises (219):

1. What procedure should you use for demand call-ins?

2. What procedure(s) should you use for routine non-NSN items?

220. State the purpose of AF Form 601b, Custodian Request/Receipt.

AF Form 601b (fig. 1-17). You cannot order equipment, such as test equipment or trainers, by the same method that you use for supplies/parts. You, as the equipment custodian (the person responsible for all equipment), must order your equipment through the allowance and authorization (A&A) Section.

The custodian uses the AF Form 601b to request allowance and authorization change and/or issue and turn-in of equipment. The A&A section also uses this document to notify custodians of action taken on requests. (Before submitting a request, carefully screen the custody receipt listing to insure that the desired item or a suitable substitute is not on hand). The custodian obtains the signature of the organization commander or designated representative, retains one copy, and forwards the remaining copies to the A&A section. You will be given special training if you are asked to be an equipment custodian.

Exercises (220):

1. What type of supplies are ordered with an AF Form 601b?

221. State the purpose of the DD Form 1570 series condition tags; and from given situations, state the proper tag to use and how to fill it out.

The custodian of all Air Force equipment which is not in-use must be readily identifiable. The Air Force uses a Department of Defense system of color-coded tags for the purpose of identifying equipment and its condition. The most frequently used tags that you will see are yellow, green, red, and brown.

New items received directly from the manufacturer will not have a condition tag on them, but everything repaired or inspected by Air Force personnel should have a condition tag attached. Anytime you turn an item in to base supply, a condition tag must be attached.

Condition Tags. The purpose of the condition tags is to show the condition of USAF property. As a maintenance man, you will be required to fill out these tags and to know what condition the tags reflect.

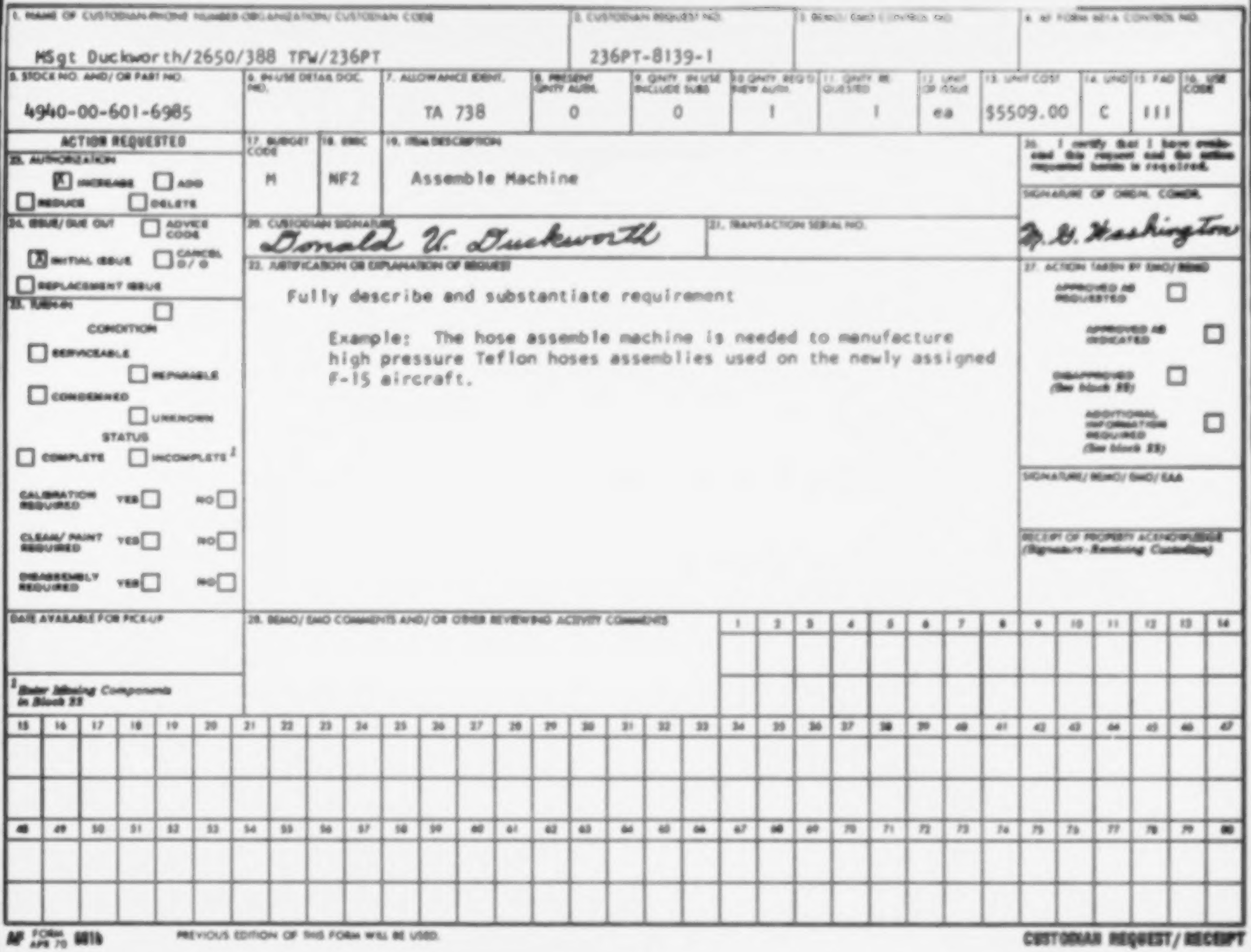
When a part is removed from any equipment, you will fill out an AFTO Form 350, Reparable Item Processing Tag, and attach it to the part. This part is then routed to the responsible shop for repair. The exact action taken at the shop—i.e., whether it is tested, repaired, or sent to a higher echelon for maintenance action—depends on the setup of your particular organization. Nevertheless, somewhere along the line, the part is tagged with the appropriate condition tags. Once again, your main concern with these tags is to know what conditions they reflect. Thus, we will discuss the condition tags with this in mind.

DD Form 1574 and DD Form 1574-1 (yellow tag and label). The DD Forms 1574, Serviceable Tag—Materiel, and 1574–1, Serviceable Label—Materiel, are yellow and have the same format; their only difference is that the 1574 form is a tag, and the 1574–1 form is a gummed label. A properly completed 1574 is shown in figure 1-18. The presence of one of these forms on a piece of equipment denotes that the equipment is in a serviceable condition. Both forms are used for this purpose; and they may be placed on used as well as new equipment, since the forms indicate that, in the opinion of the inspector, the equipment is in serviceable condition, good for the purpose for which it was intended.

Most of the entries made in the blocks are self-explanatory by their titles. However, a few words should be said about the Serial Number/Lot Number and the Contract or Purchase Order No. blocks. Normally the serial number is entered in the Serial Number/Lot number block. If no serial number is given for the part, NA is entered. The contract or purchase order number is entered by Supply personnel when the number is available.

DD Form 1577-2 (green tag). The DD Form 1577-2, Unservicable (Reparable) Tag Materiel (see fig. 1-19), is green and is used to indicate that the item requires work to restore it to a serviceable condition; in other words, the item is reparable. This means that items which are removed from service but which still appear serviceable are tagged with a 1577–2 form whenever a reasonable doubt exists as to their serviceability. However, when items are obviously not serviceable, they are inspected to ascertain their repair cost; and if the cost is within the prescribed allowance, they are "green tagged" and processed through the proper repair channel to be restored to a serviceable condition. The entries made in the block either have been previously discussed or are self-explanatory by the titles of the blocks.

DD Form 1577 (red tag). In sharp contrast to the foregoing forms is DD Form 1577, Unserviceable (Condemned) Tag Materiel, shown in figure 1-20. This tag is used to indicate either that the article to which it is attached is unsuitable for restoration to a serviceable condtion or that it is of no further use to the Air Force in the function for which it was manufactured or authorized. We can say that equipment is placed in a condemned category either because of its condition or by administrative action. When equipment is in a condemned condition, the decision is made by a qualified inspector and is the result of one of two situations: either the article cannot be repaired or the cost of repair would exceed the established maximum repair allowance. When equipment is administratively condemned, the judgment of an inspector does not enter into the situation, since this action is taken by AFLC or



1. NAME OF CUSTODIAN/PHONE NUMBER/ORGANIZATION/CUSTODIAN CODE MSgt Duckworth/2650/388 TFW/236PT	2. CUSTODIAN REQUEST NO. 236PT-8139-1	3. BEMO/EAID CONTROL NO.	4. AF FORM 601A CONTROL NO.

5. STOCK NO. AND/OR PART NO. 4940-00-601-6985	6. IN-USE DETAIL DOC. NO.	7. ALLOWANCE IDENT. TA 738	8. PRESENT QNTY AUTH. 0	9. QNTY. IN USE INCLUDE SUBS 0	10. QNTY. REQ'D NEW AUTH. 1	11. QNTY RE-QUESTED 1	12. UNIT OF ISSUE ea	13. UNIT COST $5509.00	14. UND C	15. FAD 111	16. USE CODE

ACTION REQUESTED

23. AUTHORIZATION

☒ INCREASE ☐ ADD

☐ REDUCE ☐ DELETE

17. BUDGET CODE: M

18. ERRC: NF2

19. ITEM DESCRIPTION: Assemble Machine

26. I certify that I have examined this request and the action requested herein is required.

SIGNATURE OF ORGN. COMDR.: M. G. Washington

24. ISSUE/DUE OUT

☐ ADVICE CODE

☒ INITIAL ISSUE ☐ CANCEL D/O

☐ REPLACEMENT ISSUE

20. CUSTODIAN SIGNATURE: Donald U. Duckworth

21. TRANSACTION SERIAL NO.

22. JUSTIFICATION OR EXPLANATION OF REQUEST

Fully describe and substantiate requirement

Example: The hose assemble machine is needed to manufacture high pressure Teflon hoses assemblies used on the newly assigned F-15 aircraft.

25. TURN-IN ☐

CONDITION

☐ SERVICEABLE

☐ REPAIRABLE

☐ CONDEMNED

☐ UNKNOWN

STATUS

☐ COMPLETE ☐ INCOMPLETE [1]

CALIBRATION REQUIRED YES ☐ NO ☐

CLEAN/PAINT REQUIRED YES ☐ NO ☐

DISASSEMBLY REQUIRED YES ☐ NO ☐

27. ACTION TAKEN BY EMO/BEMO

APPROVED AS REQUESTED ☐

APPROVED AS INDICATED ☐

DISAPPROVED (See block 28) ☐

ADDITIONAL INFORMATION REQUIRED (See block 28) ☐

SIGNATURE/BEMO/EMO/EAA

RECEIPT OF PROPERTY ACKNOWLEDGED (Signature Receiving Custodian)

DATE AVAILABLE FOR PICK-UP

[1] Enter Missing Components in Block 22

28. BEMO/EMO COMMENTS AND/OR OTHER REVIEWING ACTIVITY COMMENTS

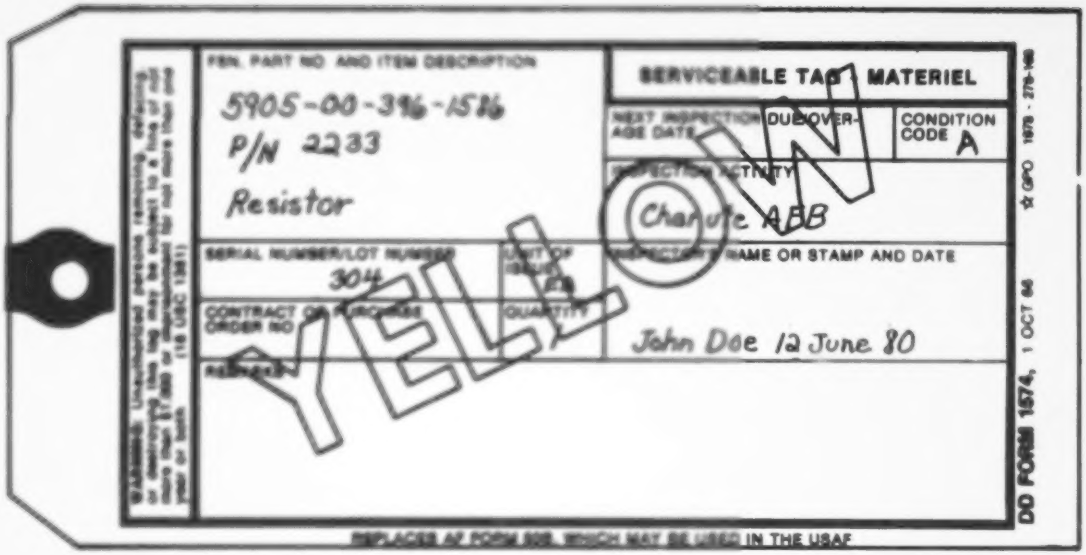
1	2	3	4	5	6	7	8	9	10	11	12	13	14

15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47

48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80

AF FORM APR 70 601b PREVIOUS EDITION OF THIS FORM WILL BE USED. CUSTODIAN REQUEST/RECEIPT

Figure 1-17. AF Form 601b.

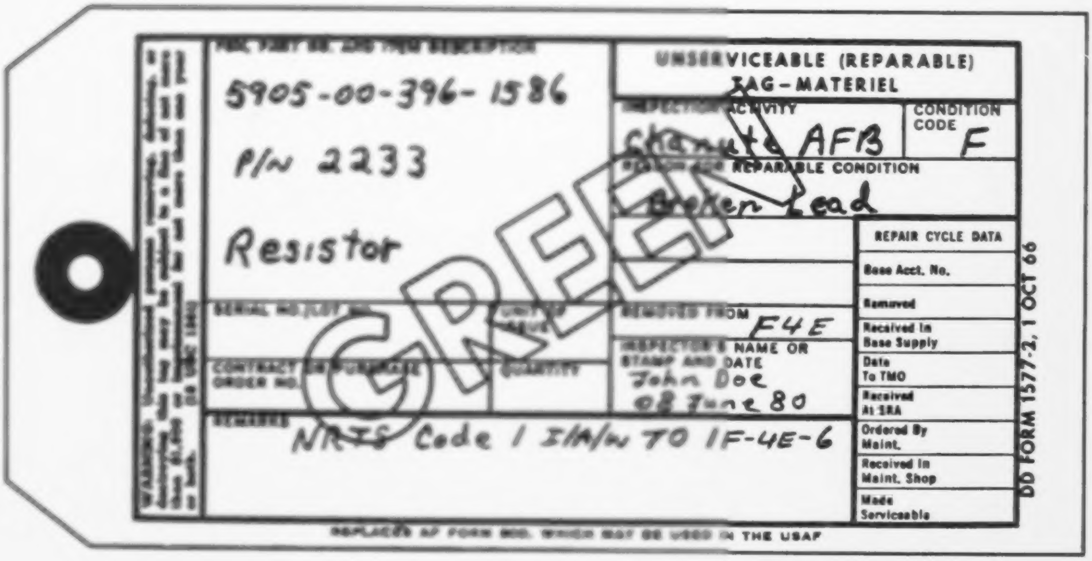


FSN, PART NO. AND ITEM DESCRIPTION 5905-00-396-1586 P/N 2233 Resistor	SERVICEABLE TAG - MATERIEL
	NEXT INSPECTION DUE/OVERAGE DATE
	CONDITION CODE A
	INSPECTION ACTIVITY Chanute ABB
SERIAL NUMBER/LOT NUMBER 304	UNIT OF ISSUE EA
CONTRACT OR PURCHASE ORDER NO.	QUANTITY 1
	INSPECTOR'S NAME OR STAMP AND DATE John Doe 12 June 80
REMARKS	

DD FORM 1574, 1 OCT 66 ☆ GPO 1978 - 278-148

REPLACES AF FORM 808, WHICH MAY BE USED IN THE USAF

Figure 1-18. DD Form 1574 (yellow).



FSN, PART NO. AND ITEM DESCRIPTION 5905-00-396-1586 P/N 2233 Resistor	UNSERVICEABLE (REPARABLE) TAG-MATERIEL
	INSPECTION ACTIVITY Chanute AFB
	CONDITION CODE F
	REASON FOR REPARABLE CONDITION Broken Lead
SERIAL NO./LOT NO.	UNIT OF ISSUE
CONTRACT OR PURCHASE ORDER NO.	QUANTITY
	REMOVED FROM F4E
	INSPECTOR'S NAME OR STAMP AND DATE John Doe 08 June 80
REMARKS NRTS Code 1 I/A/W TO 1F-4E-6	

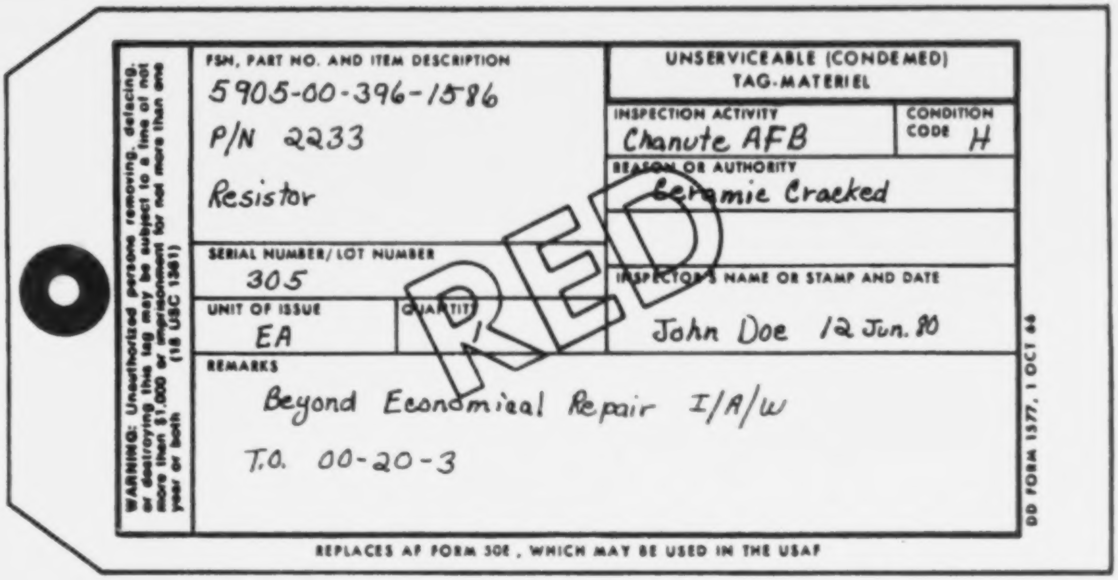
REPAIR CYCLE DATA	
Base Acct. No.	
Removed	
Received In Base Supply	
Date To TMO	
Received At SRA	
Ordered By Maint.	
Received In Maint. Shop	
Made Serviceable	

DD FORM 1577-2, 1 OCT 66

REPLACES AF FORM 808, WHICH MAY BE USED IN THE USAF

Figure 1-19. DD Form 1577-2 (green).

140



WARNING: Unauthorized persons removing, defacing, or destroying this tag may be subject to a fine of not more than $1,000 or imprisonment for not more than one year or both (18 USC 1361)

FSN, PART NO. AND ITEM DESCRIPTION
5905-00-396-1586
P/N 2233
Resistor

UNSERVICEABLE (CONDEMED) TAG-MATERIEL

INSPECTION ACTIVITY: Chanute AFB
CONDITION CODE: H
REASON OR AUTHORITY: Ceramic Cracked

SERIAL NUMBER/LOT NUMBER: 305
UNIT OF ISSUE: EA
QUANTITY: 1
INSPECTOR'S NAME OR STAMP AND DATE: John Doe 12 Jun. 80

REMARKS
Beyond Economical Repair I/A/W
T.O. 00-20-3

RED

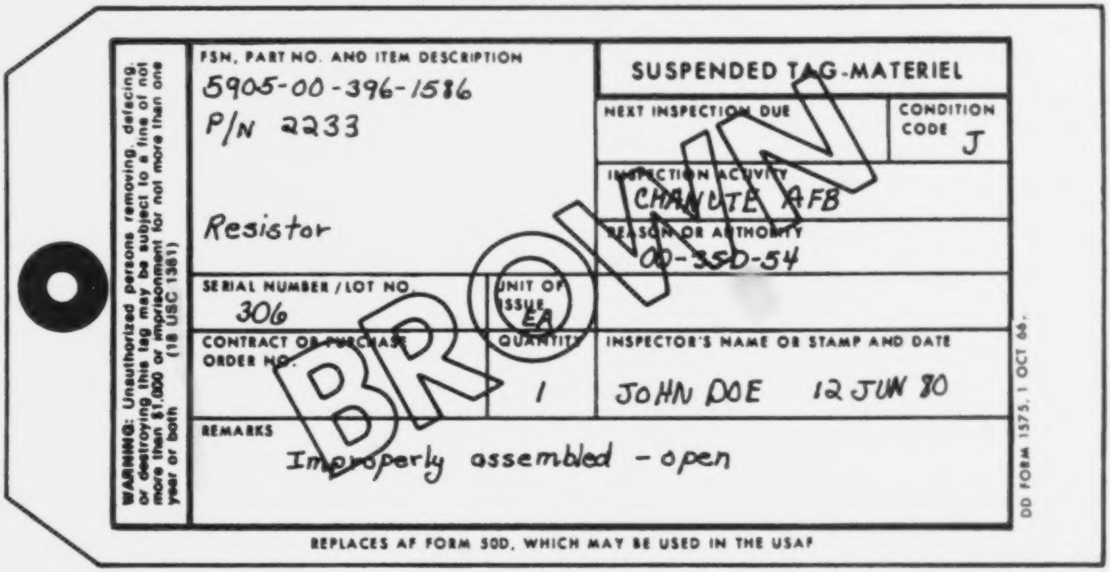
DD FORM 1577, 1 OCT 66

REPLACES AF FORM 30E, WHICH MAY BE USED IN THE USAF

Figure 1–20. DD Form 1577 (red).

higher authority. Administrative condemnation exists to prevent further use of inadequate equipment. It is applied when equipment is no longer required or when it becomes obsolete, when parts must be removed and replaced by technical order change (TOC) items or when a batch of equipment or consumable materiel is found defective. Like those on the green tag, the block entries either have been previously discussed or are self-explanatory by their titles.

DD Form 1575 (brown tag, figure 1-21). DD Form 1575, Suspended Tag—Materiel, is a rust-colored or a brown-colored tag used to indicate that no repair action As being taken on an unserviceable item because an evaluation or investigation is required to determine why the unserviceable condition exists. It is usually used on materiel deficiency exhibit items which are poorly designed, assembled, or maintained.



WARNING: Unauthorized persons removing, defacing, or destroying this tag may be subject to a fine of not more than $1,000 or imprisonment for not more than one year or both (18 USC 1361)

FSN, PART NO. AND ITEM DESCRIPTION
5905-00-396-1586
P/N 2233
Resistor

SUSPENDED TAG-MATERIEL

NEXT INSPECTION DUE:
CONDITION CODE: J
INSPECTION ACTIVITY: CHANUTE AFB
REASON OR AUTHORITY: 00-350-54

SERIAL NUMBER/LOT NO.: 306
UNIT OF ISSUE: EA
CONTRACT OR PURCHASE ORDER NO.:
QUANTITY: 1
INSPECTOR'S NAME OR STAMP AND DATE: JOHN DOE 12 JUN 80

REMARKS
Improperly assembled - open

BROWN

DD FORM 1575, 1 OCT 66

REPLACES AF FORM 30D, WHICH MAY BE USED IN THE USAF

Figure 1–21. DD Form 1575 (brown).

Exercises (221):

1. State the purpose of the following three DD Form 1570-series condition tags.
   a. DD Form 1574 and 1574-1 (yellow tag and label).
   b. DD Form 1577-2 (green tag).
   c. DD Form 1577 (red tag).

2. If you repaired a unit that had a serial number, what tag should you use? How should you fill it out?

3. If you are directed by AFLC to condemn a unit but the unit is serviceable, what tag should you use?

222. Interpret entries on the Daily Document Register.

Supply Management—Computer Products. Base supply furnishes several different reports in order to keep you informed of the status of each of your requests. They are prepared in various formats with each report serving a specific purpose.

We will discuss those reports you should know and use in an Avionics Instrument Shop. They include the Daily Document Register (D04), Priority Monitor Report (D18), DIFM Listing (R26), and Due-Out Validation Listing (M30).

Base supply sends out several documents which are printed by the computer. These products can be very helpful in monitoring and managing supply requisitions and materiel assets.

Daily document register (D04). One of these computer products, the Daily Document Register (D04), is printed for every day that a transaction was charged against the account number for your shop. Supplies and equipment appear on the same listing. To help you understand the information on the D04, the following facts are provided. The circled numbers in figure 1-22 are referenced as follows:

1. Stock number. This is the stock number that was run through the computer. Is it correct? Supply personnel put it into the computer using a keyboard much like a typewriter and could have hit a wrong key. If this has happened, you will receive the wrong part.
2. ERRC. Expendability, Recoverability, Responsibility Code. Is it expendable or reusable? Can it be repaired? Who pays for it? These are some of the questions that are answered by the ERRC code.
For example:

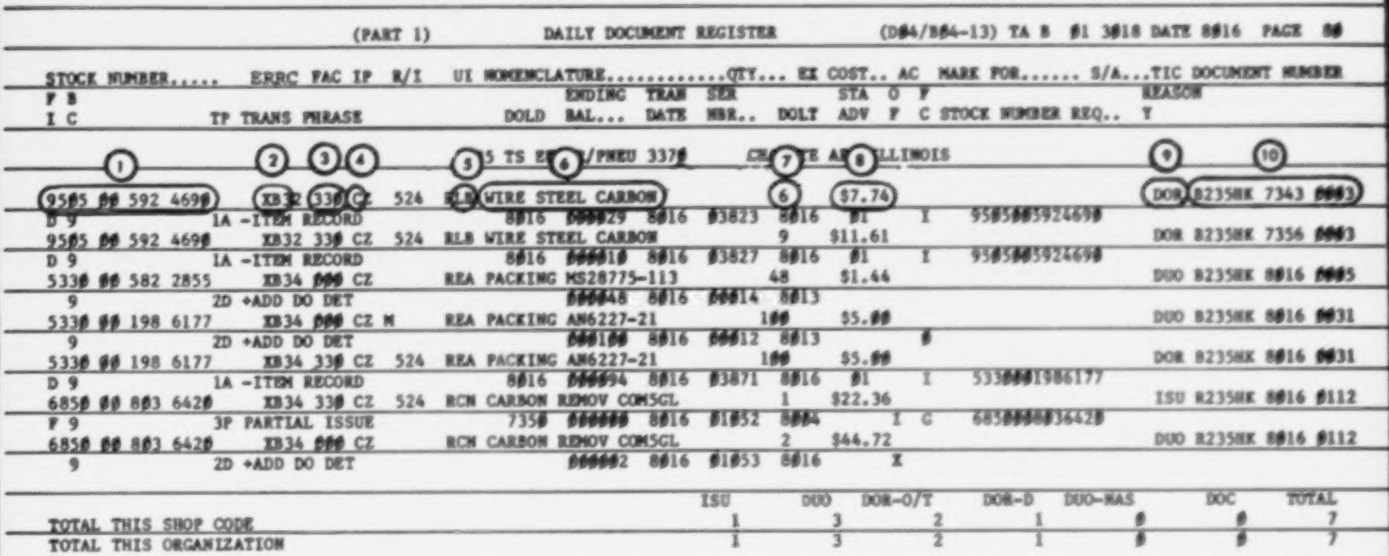
XD2—expendable at depot level only and repaired at depot.
NF1—nonexpendable, repaired at field level.
XB3—expendable at base level or repaired at base level.

The first letter will be either X for expendable supplies or N for nonexpendable equipment. The second position tells the level of maintenance at which the item is repaired or controlled. The third digit indicates whether the item is high cost (1), medium cost (2), or low cost (3).
3. FIA (Financial Inventory Account) Code. This 3-digit code tells whether the item was paid for out of squadron funds supplied by depot or if you received credit to a turn-in.

a. If the code begins with a 3 (for instance, 330), your squadron paid for the item.
b. If it begins with a 5 (such as 570), it was free.
c. If it begins with a 4 (for example, 440), you received credit for the turn-in.
d. If the code begins with a 6, (for example, 680), you did not get credit for the turn-in.
e. The code 000 indicates that no money exchanged hands.

4. Priority. This is the two-letter Urgency of Need code that you give supply when you order the item. If the first letter of the code is A, you tell supply that the mission is stopped and you must use the highest priority authorized. If the first letter is B, it means that the mission is impaired, and C is the lowest priority.
5. Unit of issue. Insure that the unit is what you expected. If it is different from your request, be sure that it converts to what you want. For example, let's say that your request stated 100 each (EA). Supply changed the unit of issue to hundred (HD), but they failed to change the quantity. You could be charged for 100 HD instead of 1 HD.
6. Nomenclature. The computer can accept as many as 19 digits in this field. It is for the customer's use and may be tailored to fit your needs. Since the nomenclature will appear on all of your listings, use a name or item description which is easily understood.
7. QTY—Quantity. Did you receive the number of items paid for? Be sure.
8. Extended cost. This is the total cost, not the cost of each item.
9. TIC (Transaction Identification Code). This code tells exactly what happened to your request. Listed below are some of the common codes you will see on the D04.

a. ISU—issue. By the time you received your D04, you should have received the item.
b. DUO—Due-Out (Back order). Base supply had to send your order some where else to be filled.
c. DOR—Due-Out Release. The part you had back-ordered is now on base. If you do not have it, you will receive it shortly. This is the same as an issue (ISU), and the amount appearing on the D04 has been paid for the item.
d. DOC—Due-Out Cancellation. Your order has been cancelled. If you did not cancel the order and still need the



```
                           (PART 1)          DAILY DOCUMENT REGISTER         (D04/B04-13) TA B  01 3018 DATE 8016  PAGE  80

STOCK NUMBER.....   ERRC FAC IP  R/I   UI NOMENCLATURE.............QTY... EX COST.. AC  MARK FOR...... S/A...TIC DOCUMENT NUMBER
F B                                                 ENDING  TRAN  SER            STA  O  F                              REASON
I C                 TP TRANS PHRASE            DOLD BAL...  DATE  NBR..  DOLT  ADV  F  C STOCK NUMBER REQ..  Y

                                                 5 TS E   /PNEU 3370       CH   TE A    ILLINOIS

9505 00 592 4690     XB32 330 CZ  524  RLB WIRE STEEL CARBON          6    $7.74                            DOR B235HK 7343 0003
D 9                 1A -ITEM RECORD            8016  000029  8016  03823  8016   01    I     95050059246 90
9505 00 592 4690     XB32 330 CZ  524  RLB WIRE STEEL CARBON          9   $11.61                            DOR B235HK 7356 0003
D 9                 1A -ITEM RECORD            8016  000010  8016  03827  8016   01    I     95050059246 90
5330 00 582 2855     XB34 000 CZ       REA PACKING MS28775-113       48    $1.44                            DUO B235HK 8016 0005
  9                 2D +ADD DO DET                   000048  8016  00014  8013
5330 00 198 6177     XB34 000 CZ M     REA PACKING AN6227-21        100    $5.00                            DUO B235HK 8016 0031
  9                 2D +ADD DO DET                   000100  8016  00012  8013        0
5330 00 198 6177     XB34 330 CZ  524  REA PACKING AN6227-21        100    $5.00                            DOR B235HK 8016 0031
D 9                 1A -ITEM RECORD            8016  000094  8016  03871  8016   01    I     5330001986177
6850 00 803 6420     XB34 330 CZ  524  RCN CARBON REMOV COM5GL        1   $22.36                            ISU R235HK 8016 0112
F 9                 3P PARTIAL ISSUE           7350  000000  8016  01052  8004      I  G     68500008036420
6850 00 803 6420     XB34 000 CZ       RCN CARBON REMOV COM5GL        2   $44.72                            DUO R235HK 8016 0112
  9                 2D +ADD DO DET                   000002  8016  01053  8016      X

                                                              ISU        DUO    DOR-O/T     DOR-D   DUO-HAS      DOC     TOTAL
TOTAL THIS SHOP CODE                                            1          3          2         1         0        0         7
TOTAL THIS ORGANIZATION                                         1          3          2         1         0        0         7
```

Figure 1-22. Daily document register (D04).

item, contact supply and find out why it was cancelled. You may have to reorder it.

e. TIN—Turn-in. This means that you turned an item in to base supply.

10. Document number. Your document number is the last entry on the right-hand side of the Daily Document Register.

11. Budget code. This code, which is not circled in figure 1-22, appears on the second line of print. It tells who paid for the item. A 9 or 1 means that your organization paid for the item.

Now that you have a general idea of what is contained on the Daily Document Register, let's talk about how to use it. A D04 is prepared for each day that any action takes place which affects your shop's account. It is a very good source of information for determining the status of parts you have on order. For example, look at document number B235HK80160112 in figure 1-20. Note that this number appears on two line entries. Apparently 3 were ordered, supply only had one which they issued, and a due-out (DUO) or back order was established for the other two. When the other two arrive on base, this document number will appear again as a DOR (due-out release) and the account will be charged $44.72 on the date of the DOR.

How much money did this shop spend on 16 Jan 80 according to the D04 in figure 1-22? Simple. Look at the financial inventory account code for each transaction. The 330 identifies each item you paid for. Move to the right and locate the extended cost of each corresponding item. Total those costs and you know how much was spent.

Exercises (222):

Refer to figure 1-22.

1. State the unit of issue for stock number 6850–00–803–6420.

2. State the transaction identifier code on stock number 5330–00–582–2855.

3. List the stock number and nomenclature of document number R235HK–8016–0112.

223. State the purpose of Supply management products.

Priority monitor report (D18). This list is provided on a daily basis for urgency-of-need A requests. and at least weekly for urgency-of-need B requests. The stock control section of Base Supply gives one copy to each organization that has due-outs (DUOs) covered by priority off-base requests (or due-ins).

In addition to your supply document number and item identification data, the following status codes will frequently be seen on the priority monitor reports. The servicing AFLC depot provides these inputs to your base supply.

BA—Item is being processed for release and shipment.

BB—Item back ordered, not immediately available.

BD—Your request is being reviewed. Additional status will be given.

BH—A substitute or interchangeable part is being supplied.

BQ—Cancelled by your request.

CK—Order rejected: item not available. Requisition next higher assembly.

A more complete listing of the status codes is contained in AFR 67–23.

DIFM Listing. This list is provided to maintenance shops as needed. It lists all recoverable and repairable property issued to or requested by a particular shop. This list is used to check and control the due in from Maintenance (DIFM) program and its assets.

Due-Out Validation Listing (M30). This list is produced monthly for urgency-of-need C due-outs or as needed. All due-outs can be listed regardless of priority. This list is used to verify that all items on order are still needed. Parts no longer needed may be red-lined to cancel the order. One copy of this list is signed by the shop supervisor and is sent back to Base Supply.

Exercises (223):

1. On which supply management product will you find status codes?

2. Which supply listing is used by a maintenance shop to control DIFM assets?

3. What is the purpose of the due-out validation listing?

CHAPTER 2

Maintenance Data Collection and Reporting

THE OLD SAYING, "The job isn't done until the paperwork is finished" was never more correct. The volume of paperwork has increased so much in today's Air Force that it is doubtful that the data processed could have been handled efficiently had not computers been developed. The question then is, "Why have all the paperwork as long as the job gets done?" The answer is that the data reporting system is a management tool. The information gathered enables maintenance managers to use their equipment, manpower, and other resources more effectively.

In support of the data reporting systems, you will be required to record your actions or to review the efforts of others on aircraft and support equipment forms. Incomplete or inaccurate maintenance data will result in erroneous manning, equipment allocation budgeting, or unrealistic work requirements.

2-1. Maintenance Data Collection (MDC) System

The Maintenance Data Collection (MDC) System provides for the recording of maintenance actions as they are done. The recorded information is then keypunched and processed fulfill management information requirements. This section of your CDC gives you a comprehensive view of the importance of the MDC System. It lists some of the reports generated from the MDC and shows some examples of graphs in case you wish to make a pictorial representation of some of these reports.

224. State the concept and benefits of the maintenance data collection (MDC) system; and state selected uses of the MDC System.

Description of the Maintenance Data Collection System. The MDC System is a system with a collection process, a storage process, and a retrieval.

During the collection process, data about the base level maintenance production are written on AFTO Form 349, Maintenance Data Collection Record, verified for accuracy, keypunched, and processed through a computer onto magnetic tapes.

The storage process begins when the data are available on the magnetic tape. This process allows for the accumulation of approximately 25 months of historical data from processed AFTO Forms 349.

The retrieval process can begin once the data are stored. In this process, the data can be retrieved through cards, reports, or magnetic tapes, depending on how USAF/PRM (Manpower), USAF/Accounting and Finance, AFLC, MAJCOM, or base requests the data. Regardless of how the data are retrieved, the significant point is that data can be retrieved.

Intended uses of data. In the MDC System, the data are intended for use on the base where collected and off the base by USAF/PRM (Manpower), USAF Accounting and Finance, AFLC, and major commands.

On base. On the base, the base-level maintenance production data are used to provide information feedback to base managers and supervisors for controlling maintenance operation.

This information is obtained from optional reports listed in AFM 66-267, *Maintenance Data Collection (MDC) System: Users Manual;* the base level inquiry system (BLIS); and the Air Force online data system (AFOLDS).

An objective of BLIS is to give maintenance managers the capability to select information from the maintenance data collected and to list that information in a desired sequence. The AFOLDS as outlined in AFM 171177, *Air Force Online Data System (AFOLDS) System Command Language (SCL) and Retrieval Language,* Volumes 1 and 2, permits retrieval information from a variety of files; for example, any file which is in a B3500 computer at a base. The AFOLDS is a user-oriented system which has access and product capability immediately or at a later date.

By using the optional report, BLIS and/or AFOLDS, base level managers and supervisors can obtain the following information from the MDC system:

a. Production information about the type of work accomplished, the work center that did the work, and the equipment on which the work was accomplished.

b. Equipment maintenance schedules and inventory information for maintenance actions that are required on a calendar basis.

c. Productive labor and indirect labor hour expenditures in either detailed or summary form. This include labor expended to support other organizations or special projects.

d. Equipment failures and discrepancy information. This information is available in composite form by type of equipment for individual equipment items.

e. Configuration status accounting. This includes information about modifications that have been completed and those that are partially completed.

In addition to the above, base maintenance managers and supervisors may obtain information concerning the cost of maintenance. This cost information is provided by the maintenance cost system (MCS), of which MDC is an input. The MCS will provide feedback in terms of dollars on these items:

a. The cost of civilian and military man-hours.

b. The cost of productive direct and indirect hours.

c. The cost of maintaining aircraft and engines for both on-equipment and off-equipment maintenance.

d. Effecting reimbursement action for transit maintenance services (TO 00–20–5).

Off base. Off-base data within the MCS System are used for information to control various programs established by Air Force and major command regulations and manuals.

The Air Force Logistics Command has been designated as over-all logistics manager for Air Force systems and equipment. This management requires base level maintenance production data. AFLC uses the data to:

a. Identify maintainability and reliability problems on Air Force equipment.

b. Establish priorities for product improvement actions.

c. Account for modifications to Air Force equipment and evaluate the effectiveness of modifications.

d. Validate inspection and time change requirements and inspection and time change intervals.

e. Identify safety deficiencies and monitor their corrective actions.

f. Validate or adjust calibration intervals.

g. Validate spares requirements.

h. Identify programmed depot maintenance requirements.

i. Compile maintenance man-hours per flying hour data.

j. Evaluate unsatisfactory materiel reports and modifications proposals from other commands or industry.

k. Compute the cost for billing the Military Airlift Command and the Air National Guard for reimbursable depot level maintenance.

l. Determine time compliance technical order (TCTO) kit distribution requirements and TCTO rescission dates.

In addition to using the data for internal AFLC management of Air Force equipment, AFLC provides:

a. In conjunction with AFSC, data on the performance and support requirements of current inventory equipment for industry to use in developing new systems and equipment.

b. Data for reports requested by Headquarters USAF, the Department of the Army and the Navy, the Inspector General (for accident investigation), and the major commands.

c. Data on computer tapes to major commands requiring comparable data use by AFLC.

d. Data on Air Force-wide repair capability to bases, major commands, and Headquarters USAF for the assessment and improvement of maintenance repair capabilities.

Besides AFLC, the data in the MDC System are intended for other off-base users, such as:

a. Major commands to determine the status of equipment modifications.

b. Headquarters USAF/PRM and major commands for validating manpower requirements.

c. Headquarters USAF Accounting and Finance for determining the cost of base level maintenance operations.

Benefits. The information provided through the MDC System is used in the management decisionmaking process, which results in many tangible benefits to Air Force Logistics, especially maintenance. These benefits are not always readily apparent to the individual involved in the documenting of data; however, a large portion of the cost of the MDC System is returned through better logistics management decisions that can be made with factual information.

Exercises (224):

1. What are the three processes of the MDC System?

2. Summarize the on-base uses of MDC data as they apply to the following topics:
   a. Productive information.
   b. Productive labor.
   c. Cost of maintenance.

3. Briefly state the off-base uses of MDC data as they apply to the following topics:
   a. Reliability problems.
   b. Safety.
   c. TCTO requirements.
   d. Manpower requirements.

4. Explain the benefits of the MDC System.

225. Point out the areas of responsibility for insuring the accuracy of MDC data.

Accuracy of MDC data. Because of the multitude of uses made of the MDC System, the data must be as accurate as possible. A continuous effort by each individual at all levels of management is required to make this system pay the greatest dividends.

As an aid in reducing errors, both base-level and AFLC computer programs provide error reports to bases and major commands. These reports should be treated as management aids, not as instruments to penalize individuals who accidentally caused errors. The full intent of these reports is to improve reporting and data utilization.

Edit procedures to detect errors are designed to check the validity of all data elements. These procedures are also designed to make cross-comparisons between many of the codes so as to insure compatibility of data. However, these edit procedures are limited by computer capability, time, program complexity, and the ability to validate such entries as serial numbers. It is, therefore, a responsibility of each performing work center supervisor to assure the completeness and accuracy of all forms prior to turning them in for keypunching. This is the supervisor of the work center identified in block 2 (work center—to be explained in detail later) of the AFTO Form 349. It is important that the errors are actually corrected, and not just "doctored" to pass edit of programs.

Exercises (225):

1. What percent accuracy do configuration managment programs require?

2. Who is primarily responsible for making certain that AFTO Forms 349 are filled out correctly before they are sent forward from the maintenance activity?

3. Who is secondarily responsible for MDC data accuracy?

226. State the contents or uses of selected MDC System reports.

MDC Reports. Maintenance data collection reports are made by machine-processing punched cards which have the AFTO Form 349 information punched on them. These reports are of two types: those that are automatically produced and those that are opted for by each respective DCM, Deputy Commander of Maintenance.

Daily runs of the punchcards result in the daily transaction testing. These same cards are accumulated, sorted again, and rerun to provide the monthly transaction listing, as well as various other monthly reports. Different "sorts" (sorting sequence) are used to provide the different reports. For maintenance units that do not have a local data service activity available, the maintenance data forms are submitted semimonthly to a parent command, which arranges for the processing. This is especially common at overseas stations. Once the maintenance data are collected and processed, you may have to review the various reports for errors and submit corrected copies to the statistical services activity. A detailed explanation of all MDC reports is beyond the scope of this discussion. Thus, we will limit our discussion to the ones you are most likely to come in contact with.

MDC Daily Transaction Error Listing (PCN SG0001B302) and MDC Daily Transaction Error Cards (PCN SG001B303). Detail cards punched from the maintenance data collection forms that contain erroneous information will be portrayed on an error listing. One copy of the Daily MDC Transaction Error Listing and the MDC error cards will be returned to Production Analysis. At least two copies of the listing should be returned to the work supervisor for correction. The work center supervisor must correct and annotate the listing in red and return it to the production analysis section. Production Analysis will provide the keypunch activity with the corrected error cards. The keypunch activity will punch a new detail card using the error card. The corrected detail cards will then be forwarded to Data Automation for normal processing.

For each detail line entry on the MDC Daily Transaction Error Listing, the computer will produce an error card in the same format as punched from the maintenance data collection forms. A short narrative description of the error will be on the listing. To effectively correct the error, the work center supervisor may have to review his or her source document or research the master ID listing, 00–20–2 series technical orders, or AFM 300–4, *Data Elements and Codes*, Volume 11 or 12.

MDC Daily Transaction Listing. This listing is mandatory to all users of the MDC System. The listing is sorted in eight sections, depending on the data submitted. Expanded edits on input data make the listed data more reliable; therefore, no correction capability is provided. However, Production Analysis and work center supervisors must make continuing periodic spot checks of the listing to insure reliability of the input data.

The reports and their PCNs are as follows:

(1) MDC Daily Transaction Listing, Section A (On-Equipment; PCN SG001B321).

(2) MDC Daily Transaction Listing, Section B (On-Equipment; PCN SG001B321).

(3) MDC Daily Transaction Listing, Section C (Support General; PCN SG 001B323).

(4) MDC Daily Transaction Listing, Section D (Indirect Labor; PCN SH 001B324).

(5) MDC Daily Transaction Listing, Section E (Parts Replaced; PCN SG001B325).

(6) MDC Daily Transaction Listing, Section F (Serially Controlled and Time Change, Remove, and Replace; PCN SG 001B326).

(7) MDC Daily Transaction Listing, Section G (Engine, Remove and Replace; PCN SG001B327).

(8) MDC Daily Transaction Summary (PCN SG001B328). This listing contains a summary of all transactions submitted by the Deputy Commander for Maintenance. Number or records, man-hours, and units are summarized by type record. In addition, a total of invalid records is provided.

MDC Monthly Transaction Listing. This listing is optional to each user of the MDC System. The listing format and totaling are the same as the MDC Daily Transaction Listing. It includes all reliable transactions processed during the month and may contain data from previous months if processed during the as-of month.

The reports and their PCNs are as follows:

(1) MDC Monthly Transaction Listing, Section A (On-Equipment; PCN SG001B501).

(2) MDC Monthly Transaction Listing, Section B (Off-Equipment; PCN SG001B502).

(3) MDC Monthly Transaction Listing, Section C (Support General; PCN SG001B503).

(4) MDC Monthly Transaction Listing, Section D (Indirect Labor; PCN SG001B504).

(5) MDC Monthly Transaction Listing, Section E (Parts Replaced; PCN SG001B505).

(6) MDC Monthly Transaction Listing, Section F (Serially Controlled and Time Change, Remove and Replace; PCN SG001–B506).

(7) MDC Monthly Transaction Listing, Section G (Engine, Remove and Replace; PCN SG001B507).

These listings are composites of all daily transaction. They are the basic source of all maintenance tasks performed and direct and indirect labor documented during the month. The format of the listings makes various analyses by work unit code and standard reporting designator relatively easy. Production and Deficiency Analysis may use these listings to determine areas of maintenance that require further investigation. Sections A and B may be used to determine those components which malfunctioned most frequently. Section E may be used by Materiel Control for forecasting future parts requirements. Section F may be used by Documentation to audit time change replacements.

MDC Work Summary. The MDC Work Summary is produced in three parts; Parts 2 and 3 each consist of four sections. All of these listings are optional to each user of the MDC System. Specific listings are as follows:

(1) MDC Work Summary, Part 1 (Direct labor by End Item; PCN SG001B511). This listing contains a summary of all direct labor expended within a DCM, by end item. This listing is the primary source of information for determining the direct labor hours expended and units produced by type maintenance against an end item. This is the source for computing man-hours per flying hours or sortie.

(2) MDC Work Summary, Part 2, Section D (Direct Labor by Work Center; PCN SG001B525). This listing contains a summary of all direct labor expended within a DCM by work center. Section A (PCN SG001B521) is summarized by the first position of the PWC; Section B (PCN SG001B522) is summarized by the first two positions of PWC; and Section C (PCN SG001B523) is summarized by the first three positions of the PWC. This listing provides work center production by end item.

(3) MDC Work Summary, Part 3, Section D (Indirect Labor; PCN SG001B535). This listing contains a summary of all indirect labor expended within a DCM, by work center. Section A (PCN SG–001B531) is summarized by the first position of the PWC. Section B (PCN SG001B532) is summarized by the first three positions of the PWC. This listing is the primary source of information for determining the indirect labor expended within a DCM, by work center.

Exercises (226):

1. What report(s) is used to correct erroneous information?

2. What does the work center supervisor do with this erroneous information?

3. What report contains a short narrative description of the errors?

4. Although MDC Daily Transaction Listing does not have correction capability, what can be done to insure the reliability of the input data?

5. What report contains a total of invalid records?

6. What report may be used to determine those components which malfunctioned most frequently?

7. For what purpose may Materiel Control use Section E of the MDC Monthly Transaction Listing?

8. What report is used as a primary source of information for determining the direct labor hours expended and units produced by type maintenance against an end item?

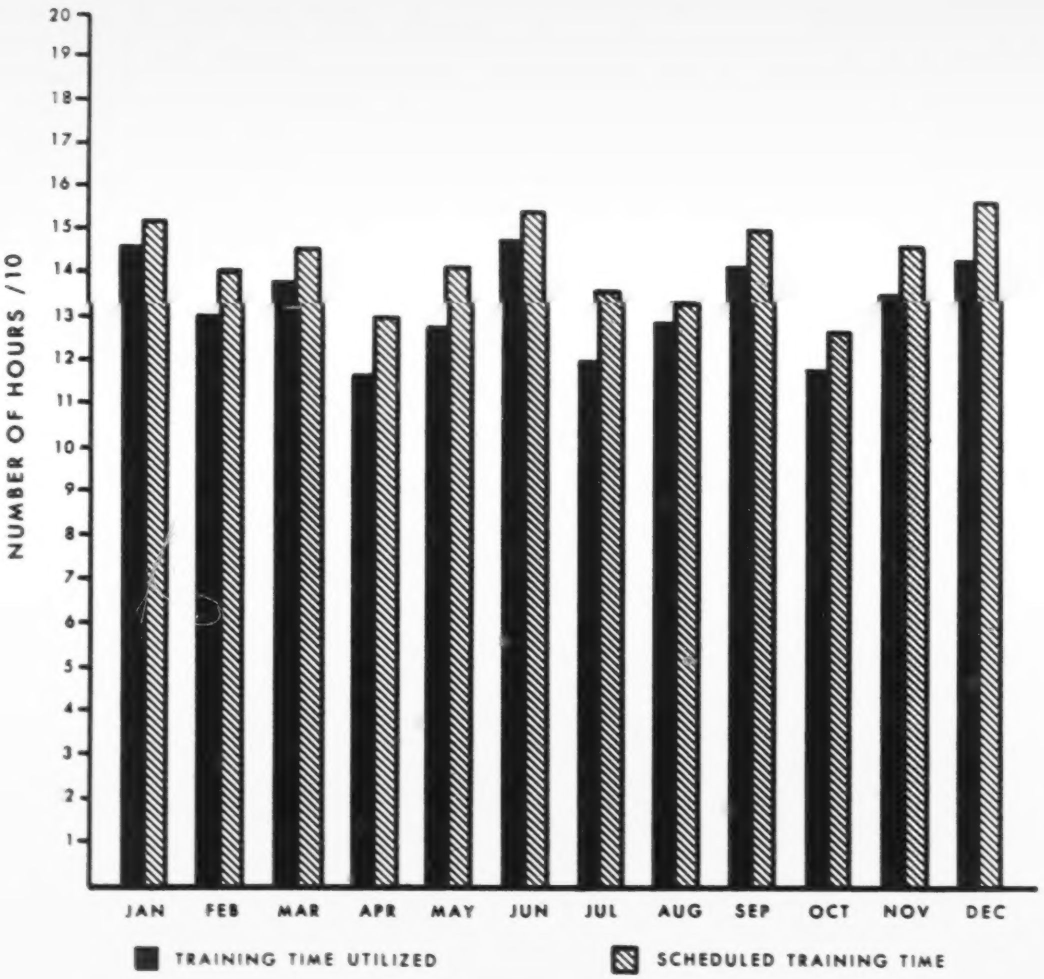


Figure 2–1. Bar graph.

9. What type of information is contained in the MDC Work Summary, Part 2, Section D?

227. Interpret a graph and identify the type of graph needed to depict given information.

Graphs. A good picture or graph can illustrate clearly and simply some point that would require a page or two of involved written explanation. You can learn from technical language, but when words are coupled with an illustration, you understand much more easily. For that reason, this chapter includes information about graphs needed by the maintenance man and the advanced supervisor.

There are many types of graphs, but we will deal briefly with only a few of them. Graphs have different purposes; they may show the relationship between two quantities, the relation of the part to the whole, a comparison of amounts, rate of change, or an increase over a given period of time. The following brief discussion shows how some graphs serve these purposes.

Bar graph. The bar graph (see fig. 2-1) uses vertical or horizontal bars. It usually records statistics. In this figure, the bar graph shows the number of training hours given each month to flightcrews as compared with the scheduled training hours for each month. This particular graph is an example of a "double bar graph." Notice that in this type graph the units on the left are shown with a multiplier—in this case, 10.

Circle graph. The circle graph, shown in figure 2-2, is called the "pie" graph because it shows the relationship of the parts to the whole and comparisons of amounts of slices. This type of graph is commonly used by big companies in advertisements to show how each dollar that they take in is

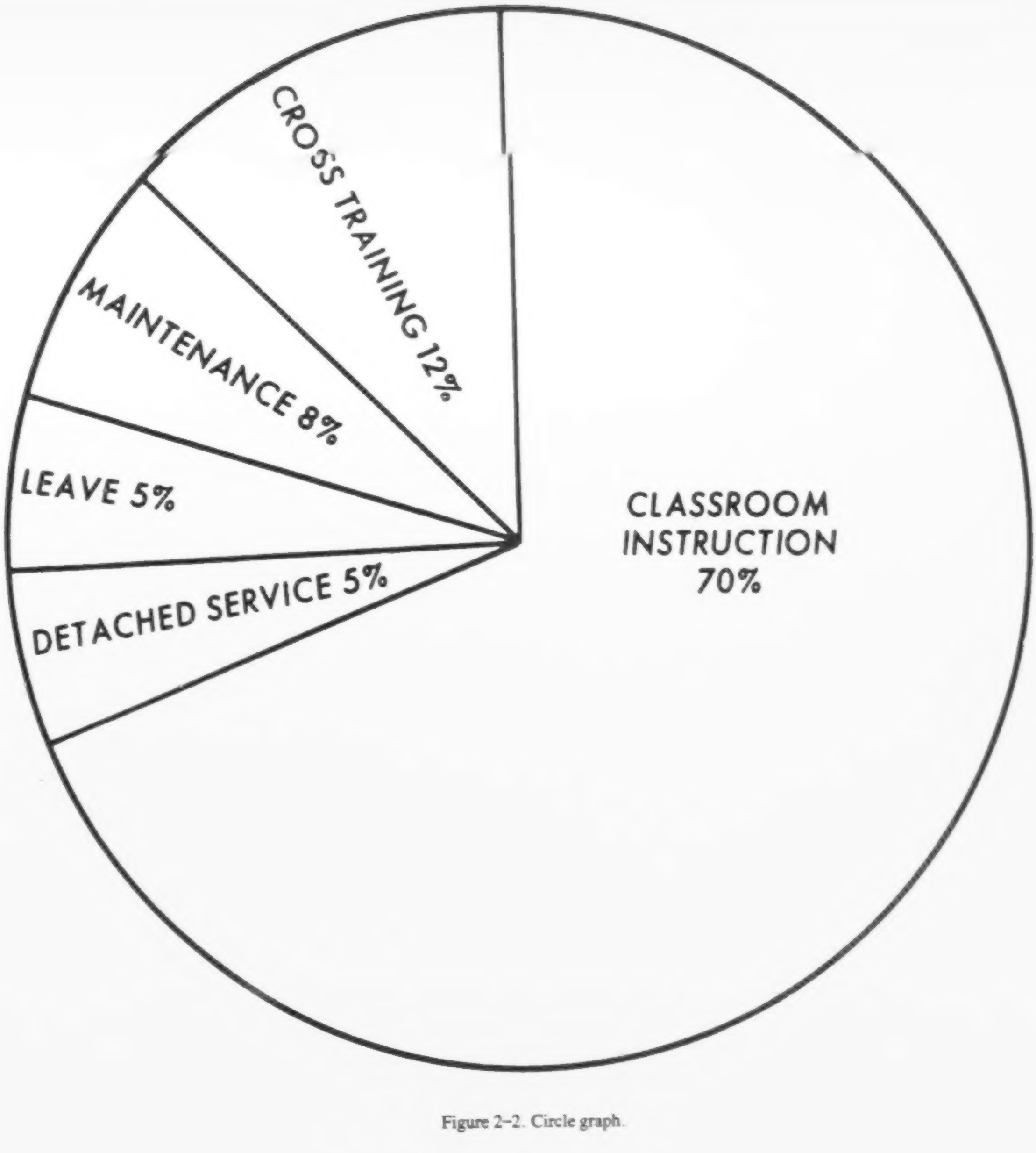


Figure 2–2. Circle graph.

spent. In our example, the graph illustrates how the time of an instructor is divided over a year's period. For example, the total time is broken down in five parts. The values used are hypothetical. The purpose of the chart is only to illustrate a possible use of a circle graph.

Other types of graphs that are very similar to those shown may be used to illustrate statistics. There is no need to elaborate on them in this course. However, it should be evident that graphs can be very useful in any organization.

Exercises (227):

1. Using figure 2-1, determine in which month most of the scheduled training time was actually used. Approximately how many hours were scheduled that month? How many were used?

2. What type of graph best illustrates the relationship of parts to the whole?

2-2. Maintenance Data Collection Forms

There are two basic maintenance data collection forms—AFTO Form 349, Maintenance Data Collection Record, and AFTO Form 350, Reparable Item Processing Tag—used to document data for the MDC System. But before we cover these AFTO Forms, you need to have an understanding of job control numbers (JCNs) and standard reporting designators (SRDs).

228. Given various work situations, determine the proper use of the job control number.

Job Control Number. The job control number (JCN) provides a means to tie together all maintenance actions taken, both on-equipment and off-equipment, relating to a specific job. Job control numbers are assigned any time man-hours are expended or parts are consumed in satisfying a maintenance requirement whether it be a discrepancy, an inspection, or a TCTO. Every action taken that is related to a job, regardless of work center, time, or place, will carry the same job control number that was originally assigned to the job. This procedure is necessary to permit control of all related actions. It also provides the capability to tie them together in the data system to identify the total job for analysis purposes. The first three characters of the JCN constitute a number for the Julian date, such as 041 for 10 February. The last four characters are used to identify jobs. They normally consist of a daily job sequence number, such as 0001 for the first job of the day. Using the cited examples, the JCN would be 0410001. Rules for assigning job control numbers are listed in Table 2–1.

Blocks of JCNs may be assigned to equipment, organizations, or certain recurring maintenance actions in accordance with the requirements in TO 00–20–2 and the procedures contained in AFR 66–1.

Exercises (228):

1. What date and job number would job control number 0460431 indicate?

2. You are bench checking 20 identical indicators just received from Supply. How many JCNs would be used for bench checking the servos?

3. You accomplish a TCTO an an aircraft component during a major inspection. Would the TCTO work be documented under the inspection JCN or under the TCTO JCN?

4. During a major inspection you discover a defective component. Would the defective component be documented under the inspection JCN or would a new JCN be assigned?

5. You are doing general support work other than inspections. This work takes 2 days. Will this second day of maintenance require a new JCN?

229. State the function and purpose of the standard reporting designator.

Standard Reporting Designator. The standard reporting designator (SRD), previously the equipment classification (EQ/CL), code consists of three characters, and is assigned to identify aircraft, missiles, ground communications-electronics-meteorological equipment, AGE, trainers, engines, ground-launched missile real property installed equipment, munitions, and precision measurement equipment. Codes are also assigned for research and development and shop work. Most of the standard reporting designators are assigned to specific equipment, such as ABG for B52–G aircraft. Some of the codes are assigned by category of equipment or work, such as for nonregistered AGE and for ship work that is not identified to a weapon or support system. The authorized standard reporting designators are contained in TO 00–20–2.

The first character of the standard reporting designator identifies a general type of equipment, such as "A" for aircraft and "B" for ground radio equipment. The last two

TABLE 2-1
ASSIGNMENT OF JOB CONTROL NUMBERS

S	A	B
T E P	Maintenance Control, Munitions Control, or Activities Assigned Blocks of Job Control Numbers Will	For
1	Assign an individual unique job control number	the removal and replacement of serially controlled items or time change items
2		engine changes
3		equipment discrepancies (failure defects, damage or similar conditions)
4		TCTO actions on end items or commodity TCTOs on installed items
5		cannibalization actions*
6		hourly or calendar phase inspections**
7		periodic, hourly postflight, major isochronal, minor isochronal, or ground CEM (7 day or greater interval) inspections**
8		special inspections, when not accomplished during the scheduled inspections identified in steps 6 and 7
9		the correction of each discrepancy which was written up during a scheduled inspection
10	Assign either an individual unique or grouped job control number (local option)	the accomplishment of support general work other than inspections
11		the accomplishment of daily preflight, basic postflight, thruflight, shift verification, scheduled storage, and ground CEM (less than 7 day interval) inspections
12	Assign a grouped job control number	reporting indirect labor
13		the accomplishment of commodity TCTOs on spare items that were not removed from end items for modification and reinstallation
14		the functional check of items withdrawn from supply

NOTE: When maintenance actions are the result of any inspection identified in steps 6 and 7, the unique JCN will have the same first four digits of the JCN that were assigned to the inspection and the last three digits will be from the block of job sequence numbers reserved for that inspection.

TABLE 2-1 (Cont'd)

*The same JCN will be used for both the "T" (removal) and "U" (replacement) action.

**These inspections have unique 4th digit requirements. For example, a 1st phase inspection might have a JCN of 041 A001. The fourth position JCN entries are listed in TO 00-20-2.

characters of the equipment classification code identify an individual item of equipment (when used with the prefix), such as BKR for the AN/GRT-3 radio set. Standard reporting designator codes are not assigned for installed engines because the end item equipment classification code is used for recording maintenance on installed engines.

Standard reporting designators are used in computer programs to facilitate data processing for specific equipment, such as the B-52H; by like groups of equipment, such as all series of B-52s; or by general types of equipment; or to segregate information by individual types of end items. This enhances both on-base and off-base data retrieval.

Exercises (229):

1. State the function of the two parts of the standard reporting designator.

2. What is the purpose of SRD codes?

230. State the documentation categories of MDC data and identify some of the uses of the AFTO Forms.

Documentation Categories. All MDC data are grouped into one of three categories. Data documented to describe maintenance performed on end items of equipment are categorized as "on-equipment." Data documented to describe maintenance performed on assemblies, subassemblies, or components apart from an end of item of equipment are categorized as "off-equipment." The third category, "indirect labor," identifies those productive indirect hours that are expended for leaves, details, compensatory time off, training, and alert duty. By documenting within the appropriate categories, both on base and off-base users will have available this data, which fully describes where, when, what, and how maintenance production resources are used.

MDC Forms. The AFTO Form 349 (figs. 2-3 and 2-4) is used to document all three categories of data. In addition, the form is used for purposes other than MDC documentation. In units supported by the Maintenance Management Information and Control System (MMICS), the AFTO Form 349-3, Maintenance Data Collection Record (Automated), is also used. This form is a three-part form designed for use with the TC521 remote terminal. Excluding the first part of the form, AFTO 349-3 is nearly identical to the AFTO Form 349 in format and use.

The AFTO Form 50 (fig. 2-5) provides an interface between on- and off-equipment documentation.

AFTO Form 349, Maintenance Data Collection Record. The AFTO Form 349 is the principal source document for the MDC system. (See fig. 2-3.) It is a multipurpose form used to record maintenance actions. The form also serves as a dispatch work monitoring record when used in maintenance or production control activities. A copy of AFTO Form 349 is provided to a specialist as a dispatch notice. It is also used to record the maintenance actions completed in performing the work. This provides a production credit record and an input to the MDC system for subsequent analysis and management use. This type of multipurpose form also keeps the recording burden for maintenance personnel to a minimum.

Notice in figure 2-3 that the AFTO Form 349 provides lines for recording up to five maintenance actions. This feature reduces the number of forms on which basic identification must be recorded. Another feature of the MDC system is the use of an identification (ID) number on the AFTO Form 349 for most of the Maintenance actions.

AFTO Form 350, Reparable Item Processing Tag. The AFTO Form 350 is shown in figure 2-5. This document is a two-part perforated form that is attached to components removed from equipment and items. The form serves as an identification and status tag. Use of this tag is essential to assure that the status of reparable items can always be identified. The tag is also used to provide a source document for information required in completing the AFTO Form 349 for off-equipment (shop) repair actions. This form also provides the means for controlling items flowing to and from intermediate maintenance shops. It is the accountability document for items managed under the due in from maintenance (DIFM) program outlined in TO 00-20-3, Maintenance Processing of Reparable Property and Repair Cycle Asset Control System. Dates pertaining to the base-level and depot-level repair-cycle time are also entered on this form. These dates are used as an aid in determining spares requirements.

Another important aspect of the AFTO Form 350 is that it serves as a source document pertaining to reparable this station (RTS), not reparable this station (NRTS), and condemnation actions for the supply system. This information is used as an input to the Supply computer to identify stockage requirements. Through use of a formula, this information is used to establish base stock levels on recoverable and other selected items. Information pertaining to RTS, NRTS, and condemnations is also forwarded through the supply system to AFLC. This information serves as factors for computing the worldwide spares requirements. This information entered in the supply system does not duplicate and will not match information in the MDC system because the procedures for the AFTO Form 350 are outlined in the 00-20-2 series technical orders. (This form will also be discussed in detail in a following section.)

The uses of the AFTO Forms are displayed in tables 2-2 through 2-4. Table 2-2 provides the uses of the AFTO Form 349; table 2-3 provides the uses of the AFTO Form 349-3; and table 2-4 provides the uses of the AFTO Form 350. Within each table the uses are presented by category of documentation: on-equipment, off-equipment, and indirect labor. Within these categories the uses of the forms are further arranged into subcategories of "MDC System" and "Non-MDC Systems." Whereas the uses of the forms for documenting and keypunching data for the MDC System are listed within the MDC System subcategory, the uses of

TABLE 2-2

AFTO FORM 349 USES

ON-EQUIPMENT		OFF-EQUIPMENT	
MDC SYSTEM	NON-MDC SYSTEM	MDC SYSTEM	NON-MDC SYSTEM
1. Documenting personnel actions on equipment end items such as: a. Adjustments b. Cannibalization c. Corrosion treatment d. Delayed Discrepancy Repair Action e. Inspection f. Removal of Components g. Remove to facilitate other maintenance h. Replacement of Components i. Special inspection j. Support general k. TCTOs l. Time Change items m. Troubleshooting	1. Dispatching specialists	1. Documenting personnel actions on assemblies, subassemblies, or components such as: a. Adjustment b. Assemble c. Bench Checks d. Corrosion e. Fabrication f. Manufacturing g. Scheduling calibration and repair of TO 33K-1-100 items h. Special inspection i. Support general j. TCTO	1. Dispatching specialists
2. Keypunch source for codes and data elements	2. Identifying: a. Number of specialists dispatched b. Shop dispatching c. Reason for dispatch d. Where dispatched e. Length of dispatch f. Delayed discrepancies	2. Keypunch source for codes and data elements	2. Identifying: a. Number of specialists dispatched b. Shop dispatching c. Reason for dispatch d. Where dispatched e. Length of dispatch
	3. Determining when to schedule maintenance, e.g., inspections, delayed discrepancies, TCTOs, etc.		3. Determining when to schedule maintenance, e.g., inspections, delayed discrepancies, TCTOs, etc.
	4. Historical records		4. Historical records
	5. Reimbursable Billing		5. Reimbursable Billing

TABLE 2-2 (Cont'd)

INDIRECT

MDC SYSTEM	NON-MDC SYSTEM
1. Documenting such as a. Alert b. Training c. Leave d. Compensatory time e. Details	1. None
2. Keypunch source for codes and data elements	

the forms for other than documenting and keypunching are listed in the Non-MDC System subcategory. Normally the Non-MDC System used are prescribed by the 00-20-2 series technical orders.

Exercises (230):

1. State the three documentation categories of MDC data.

2. The following lists some of the uses of AFTO forms. Identify each use as on- or off-equipment, MDC or non-MDC, and the type of form (refer to tables 2-2 through 2-4) you use for documentation. More than one form may apply.
   a. Bench check.
   b. Removal of components.
   c. Identify reason for dispatch.
   d. Documenting delayed discrepancy repair action.
   e. Source document for identifying NRTS action to off-base repair facilities.
   f. Historical records.
   g. Tag reparable items.

231. State the purpose of codes used on AFTO forms in the MDC System and give a brief explanation of selected codes.

Use of MDC Codes. Coded information is utilized in the MDC System to simplify recording procedures and to provide the required information in a minimum amount of space on the forms. Use of codes also facilitates data retrieval because coded information can be processed through computers to produce reports and summarized data for use in maintenance and logistics management. Since coded information is converted into meaningful data, it is important that all personnel associated with recording, processing, and analyzing assure that this information is accurate and that it is utilized for its intended purpose. The codes consist of the following: job control number, work center code, identification (ID) number, standard reporting designator code, type maintenance code, component position code, work unit code, action taken code, when discovered code, how malfunctioned code, employee number, category of labor, and command activity code.

Job Control Number (JCN). The job control number was previously explained in objective 229. You may need to review this prior to covering the next objective on filling out forms.

Work center code. The work center code consists of five characters and is used to identify organizational elements to which maintenance personnel are assigned or locations to which they may be dispatched. Standard work center codes

TABLE 2-3
AFTO FORM 349-3 USES

ON-EQUIPMENT		OFF-EQUIPMENT	
MDC SYSTEM	NON-MDC SYSTEM	MDC SYSTEM	NON-MDC SYSTEM
1. Documenting Delayed discrepancy repair action.	1. Used on the TC-521 to print input and output data from the B-3500 computer.	1. None	1. None
	2. Used to direct specialists to the correct location and provide specialists with reason for dispatch.		
Keypunch source for codes and data element.	3. Used to identify: a. Number of specialists dispatched. b. Shop dispatching. c. Reason for dispatch. d. Where dispatched. e. Length of dispatch.		

NOTE: Documentation rules for the AFTO Form 349 will apply to the AFTO FORM 349-3.

TABLE 2-4
AFTO FORM 350 USES

ON-EQUIPMENT		OFF-EQUIPMENT	
MDC SYSTEM	NON-MDC SYSTEM	MDC SYSTEM	NON-MDC SYSTEM
1. Data Source for documenting off-equipment AFTO FORMS 349.	1. Tag reparable items	1. Data source for documenting off-equipment AFTO FORMS 349.	1. Identify location of reparables during repair cycle.
	2. Tag a "No Demand Transaction" reparable (reference TO 00-20-3).		2. Identify status of reparable through the repair cycle.
	3. Identify the discrepancy of the reparable item.		3. Source document used by Standard Base Supply System to determine demand levels.
	4. Source document used by Standard Base Supply System to determine demand levels.		4. Source document for identifying NRTS actions to off-base repair facilities.
			5. Tag reparable subassemblies or components removed from reparable assemblies.

NOTE: To determine when to use the AFTO FORM 350 or applicable DD FORM 1574 or 1577 series tags refer to the 00-20-2 series technical orders and TO 00-20-3.

are used by all organizations engaged in the maintenance functions outlined in AFR 66-1, *Maintenance Management*. The standard work center codes are listed in Attachment 1 to technical order 00-20-2. The responsibilities for assigning and coordinating work center codes are outlined in AFR 66-1 and AFM 66-278, *Maintenance Management Information and Control System (MMICS)*. There are four types of work centers referred to in the maintenance data collection (MDC) system. These are:

a. The owning work center, which is the work center that has the basic custodial and maintenance responsibility for an item of equipment.

b. The performing work center, which is the work center performing a maintenance action or a work center that contributes labor towards a maintenance requirement. When a job is performed by owning work center personnel on their own equipment, they represent both the owning and performing work centers.

c. A reporting work center, which is any work center to which maintenance personnel are assigned.

d. A nonreporting work center, which is a work center in which maintenance personnel may expend man-hours, but to which no maintenance personnel are assigned. Examples of nonreporting work centers are those for maintenance contractors who provide maintenance data, or for training equipment that is not assigned to maintenance but requires maintenance support.

Identification (ID) number. The ID number consists of six characters and is used to identify equipment on which work was performed or from which an item was removed. The first character of the ID number is the first character of the owning work center code. The second character of the ID number is the first character (prefix) of the standard reporting designator code, such as "A" for aircraft, "E" for ground radar, or "M" for ground-launched missiles. The last four characters of the ID number are normally the same as the last four positions of the equipment serial number. Detailed procedures for assigning ID numbers are contained in AFM 66-267.

The ID number is a unique code, and you must understand its use in order to know how certain data elements are entered into the Maintenance Data Collection System. The ID number is entered in block 3 of the AFTO Form 349 for most maintenance actions. For on-equipment, this code is interpreted by a computer routine into the owning work center; the equipment serial number, registration number or part number, as applicable; the mission, design, and series or end item work unit code; and the standard reporting code. For off-equipment work, this same ID number will convert to owning work center and standard reporting designator code. Use of the ID number reduces the number of handscribed entries made by maintenance technicians; yet it provides multiple data element inputs to computer programs, and, thus, to the output products. This feature also minimizes errors in essential information, since up to four data elements can be accurately input by recording a single six-character ID number.

Standard Reporting Designator (SRD) code. Standard reporting designators (SRDs) were previously explained in objective 229. You may need to review this prior to covering the next objective on filling out forms.

Type Maintenance code. The type maintenance code consists of one character and is used to identify the type of work that was accomplished, such as scheduled or unscheduled maintenance. Type maintenance codes are contained in the applicable work unit code manual and in ADE MA-358-XL of AFM 300-4. Special inspections, 04 series support general work unit codes, amd maintenance performed during a special inspection will be documented using type maintenance code "S" (special inspection), excluding transient maintenance. Type maintenance code "T" will be used only for actions directly associated with time compliance technical orders.

Component position. The component position code is a one-digit character and is used to identify the position of the installed engine. For all other aircraft maintenance actions, this block may be blank.

Work unit code (WUC). The work unit code consists of five characters. It is used to identify the system, subsystem, and component on which maintenance is required, or on which maintenance was accomplished. These codes are published in work unit code manuals for each weapon and support system, and in code manuals by type of equipment for selected ground CEM, trainers, AGE, munitions, PME, and shop work. A limited number of work unit codes are assigned in a special category to identify tasks of a general nature, such as equipment servicing, cleaning, inspection, storage, ground safety, recordkeeping, weapons handling, and repetitive shop tasks. Although they are work unit codes, they are identified as "support general codes." To prevent confusion with the numerical characters "one" and "zero" alpha characters, "I" and "O" are not used in WUCs.

The first two characters of the work unit codes for support equipment identify types of equipment or end items of equipment, such as a trainer. The third and fourth characters of the work unit code identify subsystems or major assemblies, as applicable. The fifth character of the work unit code normally identifies reparable items; however, there are limited exceptions where codes are assigned for nonreparable critical parts and structural members. For AGE, the first two characters of the work unit codes identify the general type of equipment, the third character identifies the end item, and the remaining characters identify the subsystems or major assemblies and reparable components within the end item.

The first two characters of support general codes are standard in all work unit code manuals and identify categories of work, such as cleaning, servicing, or special inspection. The first character of all support general codes is a "O" (zero). The last three positions of the support general codes for scheduled and special inspections identify the inspection category or type inspection. The last three characters of the remaining support general codes are "O" (zero).

Action taken code. The action taken code consists of one character and is used to identify the maintenance action that was taken, such as the removal and replacement of a component. Action taken codes are standard for all equipment and are listed in all work unit code manuals. A complete list of authorized action taken codes is contained in AFM 300-4, Volume 2.

When Discovered Code. The when discovered code consists of one character and is used to identify when a defect or maintenance requirement was discovered, such as during a quality control inspection. These codes are listed in each work unit code manual for individual types of equipment. A complete list of authorized when discovered codes is contained in AFM 300-4, Volume 2. Individual when discovered codes may have more than one application. Only that portion of the when discovered code definition that applies to the equipment listed in the work unit code manual is to be used. For example, when discovered code D, Inflight-No Abort/During AGE Operation, would be listed in the AGE work unit code manual as D, During AGE Operation.

How malfunctioned code. The how malfunctioned code consists of three digits and is used to identify the nature of the equipment defect, such as "cracked." To provide maximum utility, these codes are also used to identify time compliance technical order status requirements or to show that a maintenance action did not involve a defect. A complete list of authorized how malfunctioned codes is contained in AFM 300-4, Volume 2, in both alphabetical definition and numerical code sequence. Only those how malfunctioned codes that are applicable will be listed in each work unit code manual. For example, how malfunctioned codes applicable only to a solid propellant missile will not be listed in ground CEM work unit code manual.

NOTE: Due to the nature of support general-type work, the recording of action taken, when discovered, and how malfunctioned codes is not required with support general work unit codes.

Category of labor code. This data element is used to differentiate types of man-hours expenditures. If all members of a maintenance crew are the same category of labor, only one line entry is required on the AFTO Form 349. If more than one category of labor (military and civilian) is performing the same maintenance task, or if overtime man-hours are expended, two or more line entries are required to reflect each different category of labor. Military and civilian workers will use category of labor codes 1 and 3, respectively, for normal duty hours. They will use category of labor codes 2 and 4, respectively, to report overtime. Care must be taken when completing the crew size and units blocks to prevent erroneous man-hours and unit data. Refer to AFM 300-4, Volume 2, CA-760, and TO 00-02-2.

Any man-hours expended by an individual technician in excess of a normal duty shift (as reflected on the master roster, normally 8 hours) must be documented as overtime. In no case can a line entry on the AFTO Form 349 have an elapsed time (difference between start and stop hours) greater than 8 hours.

Command Activity Identification code. All AFTO Forms 349 for maintenance performed on transient aircraft and equipment with no ID number assigned must have the two-position command code of the owning command entered in this block. For all other maintenance tasks, this block is optional and may be used to identify special projects, tenant support, or other actions such as for detached maintenance locations that return data to home station for processing. Reference AFM 300-4 Volume 2, ADE MA-360/CO-453.

Employee number. The employee number is a five-character identifier used to identify the individual who has recorded a maintenance action. For those bases not supported by MMICS, the first character of the employee number is the first letter of the individual's last name. The last four characters are normally the last four digits of the individual's social security account number. Employee numbers at bases not supported by MMICS are locally assigned and must be unique within a work center; a change to one position of the four-digit number element must be made to eliminate a duplication. For those bases supported by MMICS, the employee number is assigned by a computer program of the administrative system. For those units operating under AFR 66-5, *Production Oriented Maintenance Organization*, the AFSC number is used with an X in the skill level position. The employee number is unique and will be used for documenting maintenance actions.

When two or more individuals from the same work center are involved in a maintenance action, the employee number of the team supervisor or senior person will be used to record the action.

Employee numbers must be shown on the Maintenance Personnel Listing (AFM 66-278).

Exercises (231):

1. State the purpose of codes used in the MDC System.

2. What is the work center code?

3. When can an owning work center and performing work center be the same?

4. State the difference between what the computer interprets for the ID number for on-equipment and off-equipment.

5. What are type maintenance codes? Give an example.

6. Explain the difference between a support equipment WUC and a support general code.

7. What is an action taken code?

8. Would you use the same how malfunctioned codes on all types of equipment? Explain.

9. What codes should be omitted when a general support WUC is used?

10. What category of labor is used for normal duty hours?

11. When is the command activity identification used?

12. How are employee numbers assigned for MMICS supported bases?

13. When two or more individuals from the same work center are involved in a maintenance action, whose employee number is used to record the action?

232. Use the rules for documenting forms to determine which form(s) to use and to determine the appropriate entries in the blocks and/or columns on these forms.

Rules for Documentation. The rules for documenting data for the MDS System are written in a tabular form called a decision logic table (DLT). Table 2-5 through 2-12 are the DLTs covered in this objective. While reading this objective, you may have to refer back to the figures of the AFTO forms, figures 2-3 through 2-5.

Convenience of making repairs, table 2-5. Essentially the term "convenience of making repair" provides the personnel of the performing work center an opportunity to decide where the removed reparable item will be repaired. Before the decision is made as to repair location, these conditions must be met:

a. The item is a reparable item.
b. No demand for the item is placed on supply.
c. The reparable item can be returned to service.

With these conditions established, the repair will then be documented on an AFTO Form 349 as on-equipment or off-equipment. Once the documentation (on-equipment or off-equipment) is completed, the rules in table 2-5 will be used.

Table 2-5, Convenience of Making Repair, is used as an example and is read in the following manner. The first decision to be made is found in column A. Is the item being worked upon on- or off-equipment? This narrows the decision field to either rules 1 through 5 (on-equipment) or to rules 6 and 7 (off-equipment). To further narrow the decision field, column B is used. Select the rule(s) that best indicate the action taken. Example: Action taken on an on-equipment tasks is "G," replacement of bits and pieces. This narrows the decision field to rules 1, 2, or 4. Further, if the item is a recoverable item (column C), only rules 1 and 2 now apply. If the work center making the repair removes the reparable and does not reinstall the reparable before leaving the end item, then rule 2 applies and the form documentation described in rule 2, column E, must be accomplished.

Selection of which AFTO form to use for the MDC System is the subject for table 2-6. This table provides rules for determining which forms to use. The first decision to be made is found in column A. Are the work hours used to perform work that does not require the removal or replacement of a reparable item, to perform work that does require the removal or replacement of a reparable item, or to perform alert duty, details, etc.? Example: If the answer to the previous question is "does require the replacement of a reparable item," then either rule 2, 4, 6, or 8 applies. Further, if the work does not include accomplishment of delayed discrepancies (column B), this narrows it down to either rule 2 or rule 8. If your base is subject to MMICS in column C, then only rule 2 applies using Column D, you find that AFTO Forms 349 and 350 are the correct forms to use.

Rules for documenting the blocks and columns of the AFTO Form 349 for on-equipment and off-equipment are given in tables 2-7 through 2-10. These tables do not provide rules on the data codes and elements entered in these blocks and columns. These rules are determined from the appropriate 00–20–2 series technical orders. Use these tables in the same method previously discuss for tables 2–5 and 2–6. Table 2–11 shows the number of action lines to use for both on- and off-equipment documentation.

NOTE: When the AFTO Form 349–3 is used, the rules in tables 2-5 through 2-11 also apply.

Documentation of Indirect Labor, table 2-12. This table provides rules for documenting the blocks and columns of the AFTO Form 349 for indirect labor. To determine which codes to use in these blocks and columns, refer to the rules prescribed in TO 00–20–2.

There is one final bit of information that we want to give before going on to the next subject. The AFTO Form 349 does not contain a symbol block. Therefore, it is mandatory

TABLE 2-5

CONVENIENCE OF MAKING REPAIRS

RULE	A	B	C	D	E
	If the convenience of repair is documented	and the action taken	and the removed reparable is	and the workcenter that removed the reparable item	then personnel will
1	On-equipment	is documented as F, G, J, K, L, V, or Z	a recoverable item	installs the same reparable item (now serviceable) and does not leave the equipment end item until the installation is complete	insure that an AFTO FORM 350 Part II is documented and processed as a no demand transaction through production control to supply. (TO 00-20-3 for no demand transaction)
2				does not install the item (now serviceable) before leaving the equipment end item	document an AFTO FORM 350 and attach Part I to the reparable item (now serviceable) and insure that an AFTO FORM 350 Part II is documented and processed as a no demand transaction through production control to supply. (TO 00-20-2 for no demand transaction)

TABLE 2–5 (Cont'd)

3		for repair is not completed		does not install the item before leaving the equipment end items	doucment an AFTO FORM 350 and attach the form to the reparable item
4	On-equipment	is doucmented as F, G, J, K, L, V, or Z	a non-recoverable	installs the same reparable item (now serviceable) and does not leave the equipment end item until the installation is complete	not attach an AFTO FORM 350
5		for repair is not completed		does not install the item before leaving the equipment end item	document an AFTO FORM 350 and attach the form to the reparable item
6	Off-equipment	is documented as A, F, G, J, K, L, V, or Z	a recoverable item with a documented AFTO FORM 350 attached	installs the same reparable (now serviceable)	insure that the attached AFTO FORM 350 is processed through production control, and that the AFTO FORM 350 Part II is documented and processed as no demand transaction through production control to supply (TO 00-20-3)
7			a non-recoverable item with a documented AFTO FORM 350 attached		insure that the attached AFTO FORM 350 is processed through production control

TABLE 2-6

SELECTION OF WHICH AFTO FORM TO USE FOR THE MDC SYSTEM

RULE	A	B	C	D
	If the productive direct work hours are	and the work	and the base where the work is performed is	then use
1	used to perform work that does not require the removal or replacement of a reparable item	does not include the accomplishment of delayed discrepancies, overdue inspections, overdue TCTOs	subject to MMICS	the AFTO FORM 349
2	used to perform work that does require the removal or replacement of a reparable item			AFTO FORMS 349 and 350
3	used to perform work that does not require the removal or replacement of a reparable item	(does include) the accomplishment of delayed discrepancies		AFTO FORM 349-3
4	used to perform work that does require the removal or replacement of a reparable item			AFTO FORM 349-3 and 350
5	used to perform work that does not require the removal or replacement of a reparable item		not subject to MMICS	the AFTO FORM 349

TABLE 2–6 (Cont'd)

6	used to perform work that does require the removal or replacement of a reparable item			the AFTO FORMS 349 and 350
7	to perform work that does not require the removal or replacement of a reparable item	does not include the accomplishment of delayed discrepancies	not subject to MMICS	the AFTO FORM 349
8	used to perform work that does require the removal or replacement of a reparable item	does not include the accomplishment of delayed discrepancies		the AFTO FORM 349 and 350
9	used to perform alert duty, details, leave, maintenance training, or compensatory time for overtime	hours are expended as indirect		the AFTO FORM 349
10			subject to MMICS	

TABLE 2–7
AFTO FORM 349 BLOCKS TO DOCUMENT FOR ON-EQUIPMENT DATA

RULE	A	B	C
	If the equipment end item	and the productive direct work does	then personnel will document blocks *
	has an ID number assigned	NOT require the removal and replacement of a time change item, a serially controlled item, or wheels and tires	1, 2, 3, 26, and 27
2		require the removal of and replacement of a time change item, a serially controlled item, or wheels and tires	1, 2, 3, 6, 19, 20, 21, 22, 23, 24, 25, 26, 27, and 28
3	does not have an ID number assigned		1, 2, 3, 4, 5, 26, 27, and 28
4		NOT require the removal and replacement of a time change item, a serially controlled items, or wheels and tires	1, 2, 3, 4, 5, 26, and 27
5	has an ID number assigned	require an engine change	1, 2, 3, 6, 10, 11, 12, 13, 26, 27, and 28

TABLE 2–7 (Cont'd)

6	does not have an ID number assigned	is performed on an installed gas turbine or reciprocating engine and no time change or serially controlled item is removed and replaced	1, 2, 3, 4, 5, 26, and 27
7		is performed on an installed gas turbine or reciprocating engine and a time change or serially controlled item is removed and replaced	1, 2, 3, 4, 5, 6, 19, 20, 21, 22, 23, 24, 25, 26, 27, and 28
8		is support general	1, 2, 3, 4, and 5
9	has an ID number assigned		1, 2, and 3

*For documenting Block 29 refer to the appropriate 00-20-2- series technical orders.

TABLE 2-8

AFTO FORM 349 COLUMNS DOCUMENTATION OF ON-EQUIPMENT DATA

RULE	A	B	C
	If the equipment end item	and the productive direct work is	then personnel will document columns *
1	has an ID number assigned	performed on other than an installed engine	A, C, D, E, F, G, H, I, J, K and N
2	does not have an ID assigned		A, C, D, E, F, G, H, I, J, K, L** and N
3	has an ID number assigned	support general	A, C, G, H, I, J, K and N
4	has no ID number assigned		A, C, G, H, I, J, K, L** and N

* For documenting Column M refer to the appropriate 00-20-2- series technical orders.

** For optional use of Column L refer to the appropriate 00-20-2- series technical orders.

TABLE 2-9

AFTO FORM 349 BLOCKS TO DOCUMENT FOR OFF-EQUIPMENT DATA

RULE	A If the assembly subassembly or component	B and the item	C and the AFTO FORM 350	D then personnel will document blocks**
1	is a reparable item	is not a serially controlled or a time change item	is attached and Block 2 contains and ID number	1, 2, 3, 19, 20, 21*, 26 and 27
2			is attached and Block 2 is blank or the ID number is obliterated	1, 2, 5, 19, 20, 21*, 26 and 27
3			is attached and Block 2 contains a serial number and Block 6 a MDS	
4		is a serially controlled assembly requiring removal and replacement of serially controlled subassembly**	is attached and Block 2 contains an ID number	1, 2, 3, 19, 20, 21*, 26 and 27
5			is attached and Block 2 is blank or the ID number obliterated	1, 2, 5, 19, 20, 21*, 26 and 27

TABLE 2-9 (Cont'd)

6			is attached and Block 2 contains a serial number and Block 6 a MDS	
7	is a reparable item	is a time change item	is attached and Block 2 contains an ID number	1, 2, 3, 19, 20, 21, 26, 27 and 28
8			is attached and Block 2 is blank or the ID number is obliterated	1, 2, 5, 19, 20, 21, 26, 27 and 28
9			is attached and Block 2 contains a serial number and Block 6 a MDS	

* Block 21 is used when a reparable item has an ETI (Elapsed Time Indicator).

** A second AFTO FORM 349 is required to document the removal and replacement of the serially controlled item, Blocks 1, 2, 5, 19, 20, 21, 22, 23, 24, 25, 26, 27 and 28 (TO 00-20-2-10, Section II).

*** For documenting Block 29 refer to the appropriate 00-20-2- series technical orders.

TABLE 2-10

AFTO FORM 349 COLUMNS DOCUMENTATION OF OFF-EQUIPMENT DATA

R U L E	A	B
	If the AFTO FORM 350 that is attached to the reparable item	then personnel will document columns **
1	contains a command activity ID	A, C, D*, E*, F*, G, H, I, J, K, L*** and N
2	does not contain a command activity ID	A, C, D*, E*, F*, G, H, I, J, K and N

* For support general work intries not required.

** For documenting Column M refer to the appropriate 00-20-2- series technical order.

*** For optional use of Column L refer to the appropriate 00-20-2- series technical orders.

TABLE 2-11

NUMBER OF ACTION LINES TO USE FOR BOTH ON- AND OFF-EQUIPMENT DOCUMENTATION

RULE	A If the maintenance crew does	B and the work is started and completed	C then personnel will use
1	not stop for more than 15 minutes or change crew size	by the same category of labor from the same workcenter	one action line
2	stop for more than 15 minutes but does not change crew size		more than one action line
3	not stop for more than 15 minutes and does change crew size		
4	stop for more than 15 minutes and does change crew size		
5	not stop for more than 15 minutes or change crew size	and the labor category from the same workcenter changes before completion	
6	stop for more than 15 minutes but does not change crew size		
7	not stop for more than 15 minutes and does change crew size		

TABLE 2-11 (Cont'd)

8	stop for more than 15 minutes and does change crew size		
9	not stop for more than 15 minutes or change crew size	by different categories of labor from the same workcenter	more than one action line
10	stop for more than 15 minutes but does not change crew size		
11	not stop for more than 15 minutes and does change crew size		
12	stop for more than 15 minutes and does change crew size		

TABLE 2-12
DOCUMENTATION OF INDIRECT LABOR

RULE	A	B	C	D
	If the indirect in the workcenter	and the category of labor of the personnel involved is	and the number of AFTO FORMS 349 used	the personnel, using attachment V, TO 00-20-2, will make entries on
1	is alert duty*	the same	is one	the AFTO FORM 349 in Blocks 1, 2, 3, and Columns C, H, I, J, K
2		not the same		the AFTO FORM 349 in Blocks 1, 2, 3 and Columns C, H, I, J, K using separate action lines for each category of labor
3	includes one or more of the following: alert duty, compensatory time, details, leave or training	the same		the AFTO FORM 349 in Blocks 1, 2, 3 and Columns C, H, I, J, K using separate action lines for each category of labor within each category of indirect
4		not the same		the AFTO FORM 349 in Blocks 1, 2, 3 and Columns C, H, I, J, K using separate action lines for each category of labor within each category of indirect
5			is more than one	the AFTO FORMS 349 in Blocks 1, 2, 3 and Columns C, H, I, J, K using separate action lines for each category of labor within each category of indirect

*When necessary, substitute compensatory time, details, leave, or training.

that all red X and circled red X discrepancies, including those discovered and corrected during a scheduled inspection, be recorded on the AFTO Form 781A, Maintenance Discrepancy and Work Record. This is to document the "corrected by" and "inspected by" signatures. All uncleared discrepancies, regardless of symbol, must also be recorded on the AFTO Form 781A.

Exercises (232):

Use tables 2-5 through 2-12 to answer the following exercises.

1. If the convenience of repair is documented as on-equipment, the action taken is documented as "G", the removed reparable is a recoverable item, the work center that removed the reparable item installs the same reparable item (now serviceable) and does not leave the equipment end item until the installation is complete, what action will you take?

2. If the convenience of repair is documented as off-equipment, the action taken is documented as "K", the removed reparable is a nonrecoverable with a documented AFTO Form 350 attached, and the work center that removed the reparable item installs the same reparable (now serviceable), what action will you take?

3. If the productive direct work hours are used to perform work that does require the removal or replacement of a reparable item, the work does not include the accomplishment of delayed discrepancies, overdue inspections, or overdue TCTOs; and the base where the work is performed is subject to MMICS, what AFTO Forms should you use?

4. If the productive direct work hours are used to perform work that does require the removal or replacement of a reparable item, the work does not include the accomplishment of delayed discrepancies, and the base where the work is performed is not subject to MMICS, what form(s) would you use?

5. If the equipment end item has an ID number assigned and the productive direct work does not require the removal and replacement of a time change item or a serially controlled item, what blocks and columns on the AFTO Form 349 will be documented for on-equipment?

6. If the assembly, subassembly, or component is a reparable item, the item is not a serially controlled or a time change item, the AFTO Form 350 is attached and block 2 contains a serial number and block 6 an MDS, what blocks on the AFTO Form 349 will be documented for off-equipment?

7. If the AFTO Form 350 that is attached to the reparable item does not contain a command activity ID, what columns will be documented on AFTO Form 349 for off-equipment?

8. If the maintenance crew does stop for more than 15 minutes and does change crew size, and the work is started and completed by the second crew, and the labor category from the same work center changes before completion, how many line actions are required? Each line would show what?

9. If the maintenance crew does not stop for more than 15 minutes and does change crew size, and the work is started and completed by different categories of labor from the same work center, how many line actions are required? Each line would show what?

10. If the indirect labor in the work center is leave, the category of labor of the personnel involved is not the same, and the number of AFTO Forms 349 used is one, what blocks and columns will be documented on the AFTO Form 349 for indirect labor?

233. Identify the entries required for blocks on the AFTO Form 349.

Specific Entries on the AFTO Form 349. We previously mentioned that up to five related on-equipment maintenance actions may be reported on a single copy of the AFTO Form 349. (See fig. 2-3.) These actions must be covered by a single job control number against a single ID number, and they must be done by a single work center. If more action lines are required, another AFTO Form 349 containing the same job control number, ID number, and work center code is completed and the actions continued. This recording procedure also applies to off-equipment actions; however, on-equipment and off-equipment actions will not be combined on a single copy of the AFTO Form 349.

Let's assume that a malfunction on a system required the removal of four "black boxes." The removal action or removal and replacement action for all four black boxes may be recorded on a single AFTO Form 349. However, you use separate line entries in columns A through N if the work unit codes of the black boxes are different. The black boxes could be reported by a single line entry if the job control number, work unit, action taken code, how malfunctioned code, and when discovered code are all the same and a unit count of four is entered in column G. A separate AFTO Form 350 must be prepared for each item. Serially controlled and time change items (identified with an asterisk in the work unit code manual) must be recorded on an individual basis, (i.e., only one item per AFTO Form 349 or 350). Separate line entries in columns A through N are also required whenever the crew size for a specific job changes or any delay exceeds 15 minutes.

The form entry requirements in columns A through N of the AFTO Form 349 for time compliance technical order (TCTO) reporting are the same as those required for other maintenance actions with one exception. This is the recording of the TCTO data code. The first five digits of the TCTO data code number are recorded in column C; the sixth digit entered in column D; and the seventh digit entered in column E.

Entries in block 3 (SERIAL NUMBER), block 4 (MISSION, DESIGN, SERIES), and block 5 (EQUIPMENT CLASSIFICATION CODE) for on-equipment work are made only for transient aircraft and end items of equipment (except engines) for which ID numbers have not been assigned. The entries in these blocks and the resulting keypunching of this information in the allocated card columns overrides the computer program feature for converting the ID number to the weapon system or equipment and item identification. It also eliminates the ability to identify the owning work center. Therefore, strict compliance with recording requirements for serial number, MDS, and equipment classification code entries must be adhered to in order to eliminate unwarranted expenditures of recording and keypunching effort.

An entry in block 6 (TIME) is required only when (1) an engine is being removed from an aircraft, (2) the aircraft is a transient aircraft, or (3) the equipment is an ACMS item. The number entered in block 6 is aircraft time and not component time.

The priority of the work will be entered in block 7 (PRI) by the job control section or by the agency preparing the form. Priorities are determined by Job Control to identify those units of work which are of the greatest immediate need to the organization.

At the present time, no entry is made in block 8, SORTIE NO. The location where the job is to be performed is entered in block 9, LOCATION, only when the AFTO Form 349 is used as a dispatch form. Otherwise, block 9 is left blank. Blocks 10, 11, 12, and 13 are used only for engine change documentation. Blocks 14 and 15 have been provided to be used at the discretion of local management. They are sometimes used to further identify the shop initiating the form and the production inspector who looked at the work done.

Block 16 has been provided as tenant supply activity identifier, on an optional basis. You enter a two-digit code to identify both on-equipment and off-equipment work accomplished for a tenant organization. The two-digit identifier will have to be developed by local management and used when work is performed to support tenant units. If it is desired to document only on-equipment work in support of a tenant, use the ID number, thus freeing the two card columns for other local usage as directed.

The time the mechanic is scheduled to begin work is entered in block 17, TIME SPEC REQ. An entry is required in this block only if the form is used for dispatch work.

The JOB STD entries in block 18 are made for preplanned and job-control directed tasks that have job standards or averages developed. In the case of jobs for which standards or averages have not been developed, an estimate of the time required for completion is entered.

For off-equipment work, you enter the Federal Supply Classification (FSC) code for the item being repaired in block 19. You enter the part number of the item being repaired in block 20. First preference is to use the manufacturer's part number of the complete identification as it appears on the equipment data plate. You must include all dashes and slashes ~~included in the number~~ between numerics only. For those items that do not have part numbers, you enter the national item identification number (NIIN) (last nine digits of the national stock number). No entry is made for items that are locally manufactured and not stocklisted.

Block 21 is used for two different types of entries. When an entry is made, the unused portion of the SER. NO./OPER. TIME is struck out. This is done to signify whether the entry is the serial number or operating time. The serial number of time-significant or serially controlled items that are removed is entered in block 21. If the serial number exceeds 10 characters, enter only the last 10 positions. For off-equipment work involving time change items and items that have an elapsed time indicator (ETI) installed, enter the item operating time in this block. (Check local policies for possible changes.)

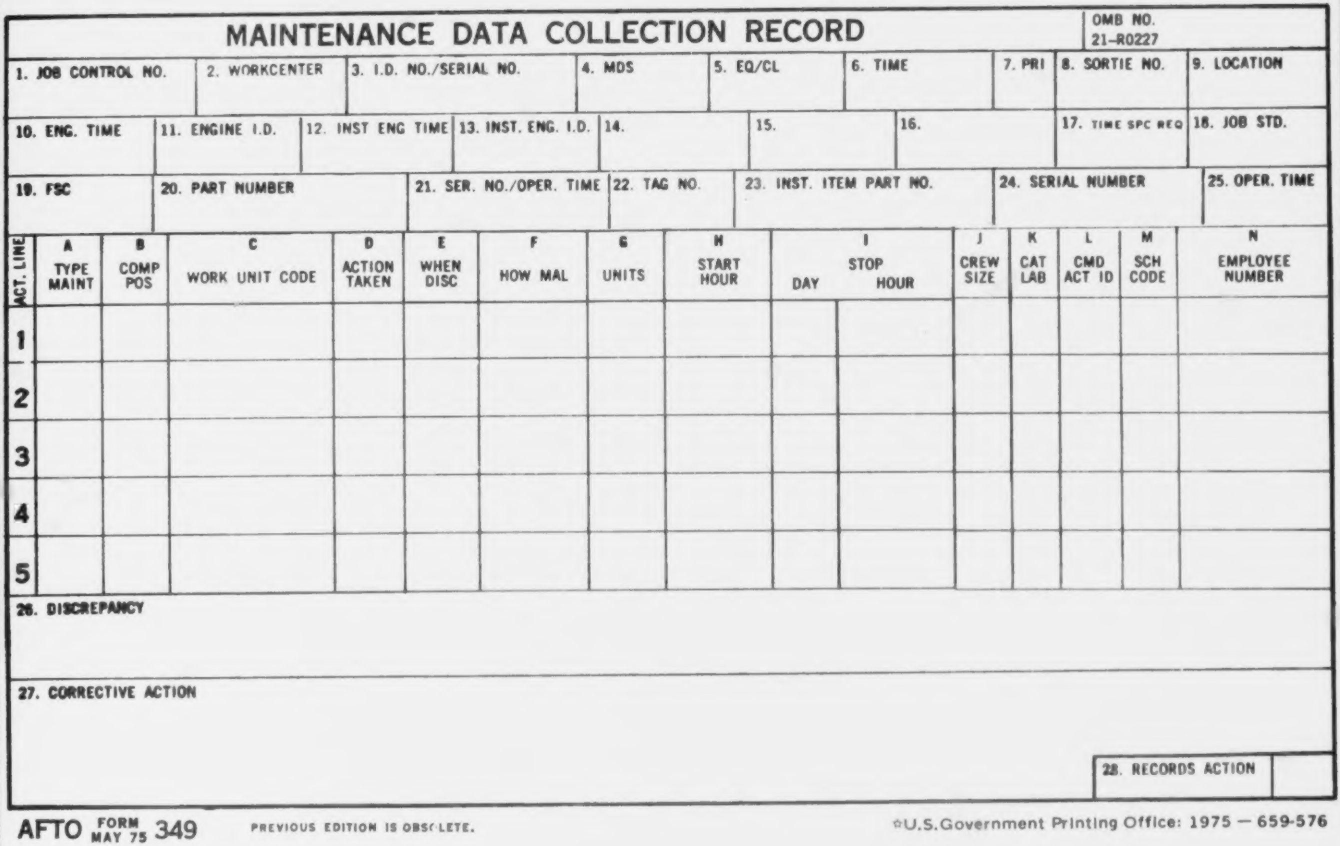
The last three digits of the AFTO Form 350 number are entered in block 22 when articles are replaced on a component during off-equipment maintenance and entries are made in block 29 (back of form) of the AFTO Form 349 because of component repairs.

Entries are required in blocks 23, 24, and 25 for time change and controlled items.

We mentioned earlier that the center part of the form is divided into five action lines. Each line is numbered and further divided into a vertical column. The lines have been numbered so that when a discrepancy requiring a bit-and-piece entry in block 29 is made, the entry can be identified by the action line number. The TYPE MAINT ENTRY in column A consists of the single digit identifier. It was discussed in objective 231.

The WORK UNIT CODE (WUC) entry in column C comes from the applicable WUC (–06 TO) manual for the equipment being repaired. Exceptions were covered in objective 231.

The ACTION TAKEN, WHEN DISC, and HOW MAL blocks are used in conjunction with the work unit code to identify a complete unit of work. You enter, in column D, the ACTION TAKEN code that identifies the action taken



MAINTENANCE DATA COLLECTION RECORD

OMB NO.
21-R0227

1. JOB CONTROL NO.	2. WORKCENTER	3. I.D. NO./SERIAL NO.	4. MDS	5. EQ/CL	6. TIME	7. PRI	8. SORTIE NO.	9. LOCATION
10. ENG. TIME	11. ENGINE I.D.	12. INST ENG TIME	13. INST. ENG. I.D.	14.	15.	16.	17. TIME SPC REQ	18. JOB STD.
19. FSC	20. PART NUMBER	21. SER. NO./OPER. TIME	22. TAG NO.	23. INST. ITEM PART NO.	24. SERIAL NUMBER	25. OPER. TIME		

ACT. LINE	A TYPE MAINT	B COMP POS	C WORK UNIT CODE	D ACTION TAKEN	E WHEN DISC	F HOW MAL	G UNITS	H START HOUR	I STOP DAY	 HOUR	J CREW SIZE	K CAT LAB	L CMD ACT ID	M SCH CODE	N EMPLOYEE NUMBER
1															
2															
3															
4															
5															

26. DISCREPANCY

27. CORRECTIVE ACTION

28. RECORDS ACTION

AFTO FORM MAY 75 349 PREVIOUS EDITION IS OBSOLETE.

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Figure 2-3. AFTO Form 349 (front).

against the item. In column E, you enter the appropriate WHEN DISC code to identify when the defect or need for the maintenance action was discovered. The WHEN DISC code must agree with the TYPE MAINT code used in column A. For example, if the discrepancy was discovered during a postflight inspection, the WHEN DISC code is H and the type maintenance code for postflights, C, must be used. The entry that identifies the HOW MAL or no-defect code which best describes the nature of the malfunction or action required on the item is entered in column F.

In column G, UNITS, you enter the number of times that action identified in column D was taken against the item identified in column C. You enter in column H, START HOUR, the time (to the nearest 5 minutes) in column I, STOP/DAY/HOUR, that the job described on this line stopped. For example, if a man works from 0700 to 1200, eats lunch from 1200 to 1300, and resumes work at 1300, two separate entries are required.

The number of persons involved in the job is entered in column J, CREW SIZE. When personnel are added to or removed from a job, that line entry must be closed out with zero units completed and a new line entry initiated for the proper number of personnel involved. You enter a two-digit category of labor code in column K, CAT LAB. Column L, CMD ACT ID, is used when a local base-assigned ID number is not used in block 3. You may wish to review objective 231 to better understand these codes.

Column M, SCH CODE, is used to update the next calibration due date of equipment requiring scheduled calibration. When a scheduled calibration is performed (may be on test equipment, torque wrenches, etc.), an X is entered in this column on the line used for calibrating the equipment. This X, when keypunched in the proper column, alerts the computer to figure the next date the equipment will be due calibration.

Column N is where you enter your employee number.

A complete description of the discrepancy or work to be performed is entered in block 26, DISCREPANCY. For on-equipment minor fix and support general maintenance, no entries are required in block 26. In this case, the entries in columns A through N are enough to identify the work. When removal and replacement of a reparable component is involved and a demand was made on the supply system, the document number assigned by Supply for the replacement of an item(s) or the requisition number is entered in block 26.

In block 27, CORRECTIVE ACTION, enter a brief but specific description of the work accomplished to correct the discrepancy. An entry is not required for on-equipment support general activities (servicing with oil, hydraulic fluid, etc.) or a minor fix. If an operational check cannot be made immediately after completing the required maintenance, the line entry is closed out. A statement of the required functional check is entered in this block. A new line entry will be completed for the functional check when it is accomplished.

A checkmark is placed in block 28, RECORDS ACTIONS, to distinguish maintenance actions that affect the historical records of an end item. If the records section initiates the form for a scheduled component replacement or a TCTO, a checkmark is made to route the form to the records section. Unscheduled time-significant replacements require the person completing the action to check block 28. This signifies that the action affects the historical records of the end item.

You enter the identification of components and parts consumed in making repairs in block 29, PARTS REPLACED DURING REPAIRS (reverse side of form—fig. 2-4), of the AFTO Form 349. Entries are required for nonreparable, nonrecoverable items. The consumption of common hardware items such as nuts, bolts, screws, washers, safety wire, clamps, common gaskets and seals, hose connections, etc., are not reported. Block 30, CONTINUATION FROM BLOCK ____________ (also on reverse side) provides space for continuation of any other block of the AFTO Form 349.

Exercises (233):

1. A maintenance action requires the services of two separate work centers. Can the maintenance be documented on a single AFTO Form 349?

2. What identifies the particular item of equipment on which work is to be performed when the prescribing document is the AFTO Form 349?

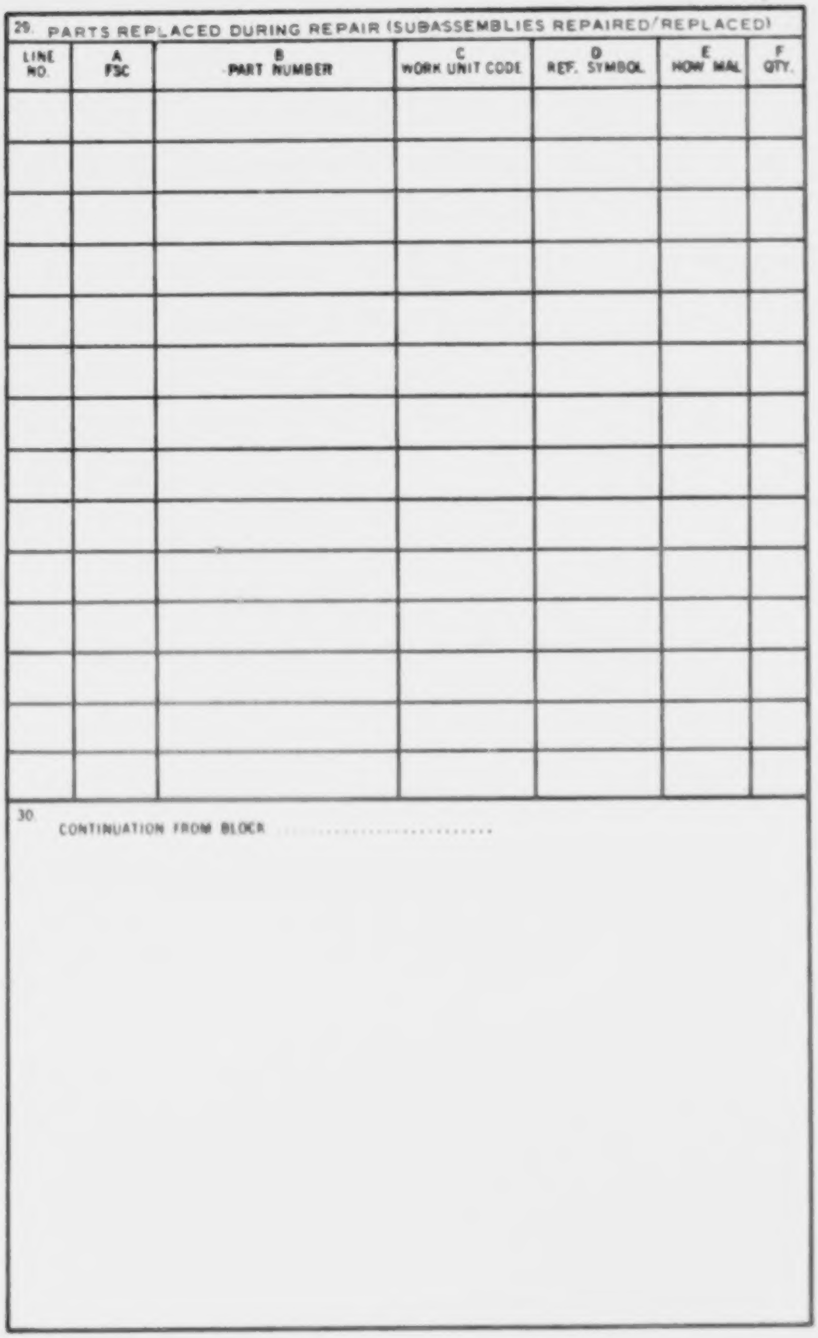
3. Who supplies the priority which is posted in block 7 of the AFTO Form 349?

4. Under what condition is block 9 of the AFTO Form 349 used?

5. The number "0900" entered in block 17 of the AFTO Form 349 indicates what?

6. If a job standard has not been established for a particular task, what entry is made in block 18 of the AFTO Form 349?

7. What item on the AFTO Form 349 identifies the specific unit on which work is being performed?



29. PARTS REPLACED DURING REPAIR (SUBASSEMBLIES REPAIRED/REPLACED)

LINE NO.	A FSC	B PART NUMBER	C WORK UNIT CODE	D REF. SYMBOL	E HOW MAL	F QTY.

30. CONTINUATION FROM BLOCK ....

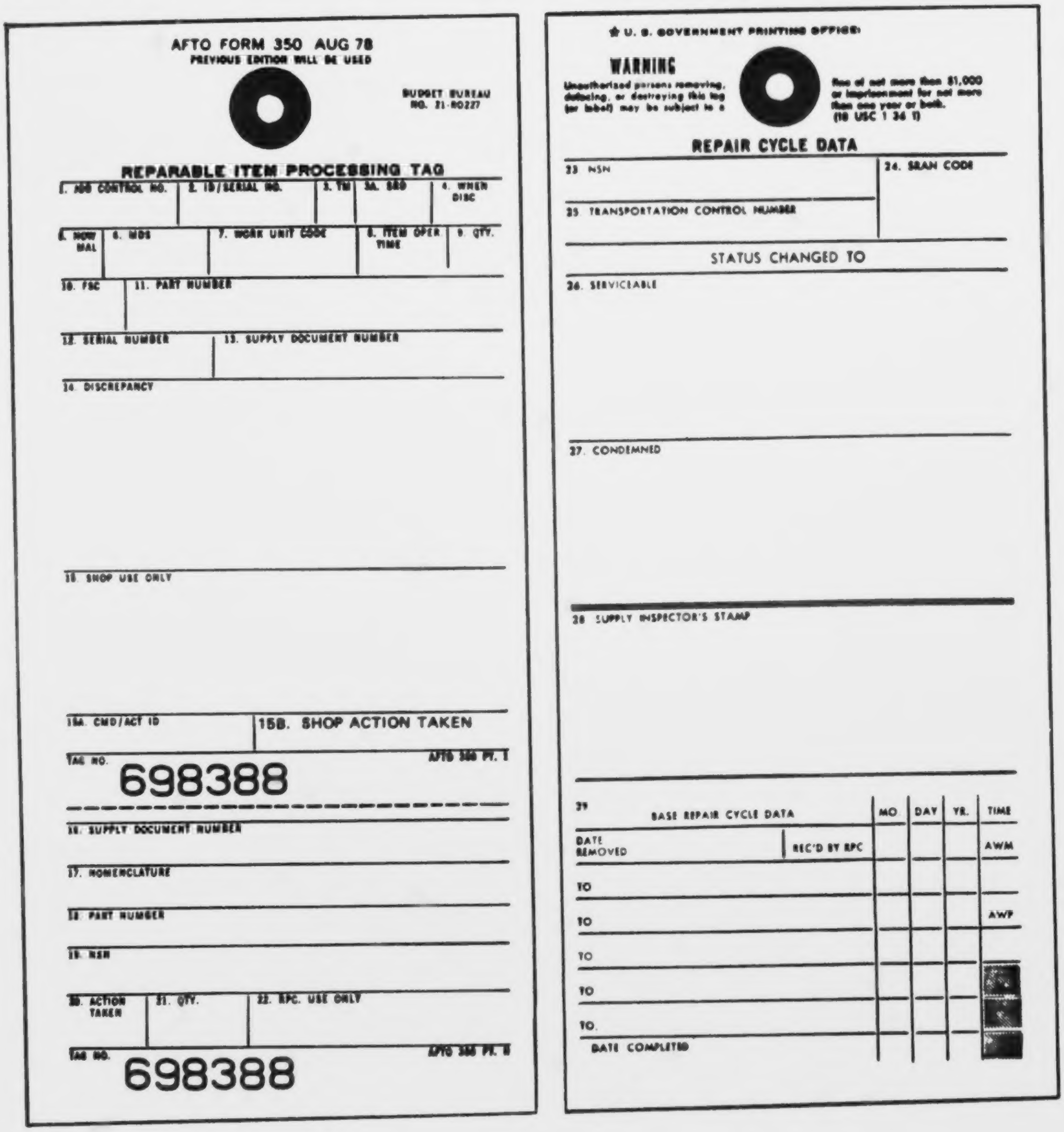
Figure 2-4. AFTO Form 349 (back).

234. State the entries required for different parts of the AFTO Form 350.

Specific entries on the AFTO Form 350. Most of the information required for this form is found in the corresponding blocks of the accompanying AFTO Form 349. Now refer to figure 2-5 as we discuss the entries for the various blocks on the AFTO Form 350.

You enter the job control number from the AFTO Form 349 in block 1 of the AFTO Form 350. If a component is broken down into subassemblies, each subassembly must be tagged with a separate AFTO Form 350 bearing the original job control number. You enter the ID number from block 3 of the AFTO Form 349 in block 2 of the AFTO Form 350. Enter the type maintenance code from block 3 (TM) and the equipment classification code in block 3A, SRD. Enter the WHEN DISC and HOW MAL codes from columns E and F of the AFTO Form 349 in blocks 4 and 5 respectively of the AFTO Form 350. No entry is required in block 6, MDS, except for transient aircraft maintenance. In block 7 of the AFTO Form 350, enter the applicable work unit code for the item removed. This is the code that was entered in column C of the AFTO Form 349.

If the item is a time-change or a serially-controlled item, the time accrued on the item is entered in block 8 ITEM OPER. TIME. In block 9, QTY, you enter the number of like items being forwarded for processing. You must fill out a separate AFTO Form 350 for each time-change or



AFTO FORM 350 AUG 78
PREVIOUS EDITION WILL BE USED

BUDGET BUREAU
NO. 21-R0227

REPARABLE ITEM PROCESSING TAG

1. JOB CONTROL NO.	2. ID/SERIAL NO.	3. TM	3A. SRD	4. WHEN DISC
5. HOW MAL	6. MDS	7. WORK UNIT CODE	8. ITEM OPER TIME	9. QTY.

10. FSC
11. PART NUMBER
12. SERIAL NUMBER
13. SUPPLY DOCUMENT NUMBER
14. DISCREPANCY
15. SHOP USE ONLY
15A. CMD/ACT ID
15B. SHOP ACTION TAKEN
TAG NO. 698388
AFTO 350 PT. I
16. SUPPLY DOCUMENT NUMBER
17. NOMENCLATURE
18. PART NUMBER
19. NSN
20. ACTION TAKEN
21. QTY.
22. RPC. USE ONLY
TAG NO. 698388
AFTO 350 PT. II

★ U. S. GOVERNMENT PRINTING OFFICE:

WARNING
Unauthorized persons removing, defacing, or destroying this tag (or label) may be subject to a fine of not more than $1,000 or imprisonment for not more than one year or both. (18 USC 1361)

REPAIR CYCLE DATA

23. NSN
24. SRAN CODE
25. TRANSPORTATION CONTROL NUMBER

STATUS CHANGED TO

26. SERVICEABLE
27. CONDEMNED
28. SUPPLY INSPECTOR'S STAMP

29 BASE REPAIR CYCLE DATA		MO.	DAY	YR.	TIME
DATE REMOVED	REC'D BY RPC				AWM
TO					
TO					AWP
TO					
TO					
TO.					
DATE COMPLETED					

Figure 2–5. AFTO Form 350.

BEST COPY AVAILABLE

serially-controlled item. Enter the Federal Supply Classification code for the removed item in block 10, FSC. The manufacturer's part number is the first preference for entry in block 11, PART NUMBER. If no part number is assigned, enter the complete identification as it appears on the data plate in block 11. In writing this number into the block, enter all dashes and slashes. For items that do not have a part number, enter the NIIN.

For time-significant and serially controlled items of equipment (marked with an asterisk in the individual equipment work unit code manual), enter the serial number of the item in block 12, SERIAL NUMBER. If the serial number exceeds 10 digits, enter only the last 10 digits. When a demand has been placed on the supply system for a like item as a replacement, enter the document number in block 13, SUPPLY DOCUMENT NUMBER. Enter a brief but specific description of the malfunction in block 14, DISCREPANCY. For items having a calendar and/or time warranty, an entry is required to reflect the date and time of installation and the date and time of removal, as well as a brief but accurate statement as to the reason for removal.

Enter a brief description of the work done on the part in block 15, SHOP USE ONLY, if the item was made serviceable. If the item is not reparable at your station, print or stamp NRTS (not reparable this station), and include the NRTS code in this block. If NRTS code 1 is used, the authority for declaring the item NRTS must be given. Normally, this authority is found under Base Level Repair Restrictions in the –6 technical manual, although any technical order which prohibits repair at your level is proper authority for using NRTS code 1. Part II of the front side of the AFTO Form 350 is to be completed by Production Control/reparable processing center (RPC). It will be detached and retained by that activity as a record copy until the item is returned from the repair shop. The entries on this side are merely copied from similar entries on the top front side of the form. Thus, there is no need to discuss them again, with the exception of blocks 20 and 22. When the repair work is completed by the shop or the item is declared NRTS and the paperwork (AFTO Form 349) is forwarded from the repair activity, the ACTION TAKEN CODE from column D of the 349 is entered in block 20. Block 22, RPC USE ONLY, is to be used locally (as necessary) by Production Control/RPC.

The backside of the AFTO Form 350 contains more spaces, some of which will concern you; others, however, will be of no interest to you. Now refer to the backside of AFTO Form 350, shown in figure 2-5.

The national stock number (same as block 19) is entered in block 23, NSN. When a component is determined to be in NRTS status, the base stock record account number (SRAN) code is recorded, or stamped, in block 24 by the shop concerned or by RPC. Block 25 is for use by Supply only. Block 26 is used by the individual who repairs the item and returns it to a servicable condition. The standard maintenance signature and date is entered in this block.

Block 27 is filled in when the item is condemned by the proper authority. If the item is expendable at your level, and if a 7-level supervisor determines that condemning the item is justified, the standard maintenance signature and the date is entered in block 27. Block 28, SUPPLY INSPECTOR'S STAMP, is reserved for Supply use only.

The Reparable Processing Center is responsible for completing all entries in block 29, except for the DATE REMOVED. You enter the date you removed the part from the aircraft or end item. The other entries on this side of Part II of the 350 tag reflect the date on which the item was received by RPC and indicate status changes for the item. Some sample entries are: To Inst Shop, To Hyd Shop, To AWM (Awaiting Maintenance), To AWP (Awaiting Parts), etc., with correspondence dates to aid in computing AWM and AWP time.

Exercises (234):

1. From what source does most of the information come that is entered in the AFTO Form 350?

2. You are filling out an AFTO Form 350 and discover that the part you are identifying has no part number nor data plate. What do yo enter in block 11 of the form?

3. Under what condition would an entry be made in block 13 of AFTO Form 350?

4. If you repair an item by replacing a component, where on the AFTO Form 350 do you make an entry telling of this action?

5. Who is responsible for making entries in block 29 on the AFTO Form 350?

2-3. Repair cycle asset control

Whether serviceable or reparable, repair cycle assets are part of the base stock level. The defective item sitting in your shop awaiting repairs could be the only spare part available to fix an aircraft. Recoverable and reparable parts produced as a result of maintenance must be controlled, repaired, and returned to supply for reuse.

235. State the operating procedures and advantages of the repair cycle asset control system.

For control purposes, all reparable item documentation will be routed through the reparable processing center or the reparable asset control center. The items will be scheduled into the shops for repair and for subsequent turn-in to Supply or for return to Maintenance for reinstallation. The reparable processing center is the functional element of Production Control that is responsible for controlling repair cycle assets within the maintenance complex. The reparable asset control center is an integrated function consisting of a reparable processing center (Production Control) and the repair cycle support unit consolidated to control repair cycle assets under an integrated system. The application of the UNIVAC 1050–II remote device provides Maintenance and Supply with a system of accounting for repair cycle assets regardless of condition. By consolidating the reparable processing center operated by Production Control and the repair cycle support unit operated by Supply, base level inventory status is improved by reporting current asset location and condition status data. The consolidation further improves Supply's response capability to satisfy maintenance demands by storage of the repair cycle serviceable assets in a supply point within the maintenance complex.

Production Control. Production Control is the central point for controlling, scheduling, and routing of repair cycle assets generated by the maintenance activity. Production Control must establish shop production flow times and daily management of in-shop production, and follow through on each item scheduled into the shops to insure that all items are promptly processed. Shop man-hour requirements will be based on estimated INW (in work) and AWM (awaiting maintenance) backlogs and on projected unscheduled shop workloads. Your shop chief will provide a personnel availability forecast to Production Control daily to assist in-shop workload planning. Production Control will attend the daily maintenance planning meeting to verify in-shop requirements and personnel availability and to establish work priorities. Production Control boards or visible files will be used as management aids to control shop actions. Sufficient data must be available on the boards or in the visible files to control all items in the maintenance repair cycle, that is, each item in AWM and INW categories.

Supply points. Supply is responsible for operation of the supply point, storage of reparables (major command option), and operation of property turn-in lines for direct routing of serviceable assets to storage points, NRTS assets to packaging and preservation, and condemned assets to the defense property disposal activity. All supply documentation is done through the remote device, if available. Under this concept, supply points and reparable processing centers are consolidated whenever possible to conserve space, manpower, and physical movement of repair cycle assets.

Selected assets, peculiar to the maintenance shops being supported, may be prepositioned in designated supply points or maintenance shops under the control of the shop chief. Normally, this latter procedure is reserved for items requiring build-up prior to issue. The repair cycle support unit is responsible for transferring the assets to the shop and processing the necessary documentation. The shop chief will advise the repair cycle support unit each time a build-up item or component is physically removed from the shop to replace a like item removed from an end item. When the item removed from the end item is restored to a serviceable condition by the shop, it will be placed in the supply point and the repair cycle support unit will be notified. The repair cycle support unit will process a paperwork turn-in for the build-up components to clear the DIFM and update repair cycle data. Build-up components removed from the end item must be turned in to Base Supply when NRTS or condemnation actions occur. Normal DIFM turn-in procedures will be used.

When the supply point for build-up items is operated by Supply, short-term hand receipts of 10 days or less will be used to control the items while they are physically in Maintenance undergoing build-up. Prior coordination between Maintenance and Supply minimizes the period that the items will be undergoing build-up. Hand receipts in excess of 10 days will be renewed daily until cleared.

Placing the demand for DIFM assets through the supply point remote device provides instant notification of a "fill or kill" condition. Thus, the time required to bring the reparable asset under control for repair action is drastically reduced. In addition, the verification of requirements which are "killed" can begin immediately after receipt of the "kill" through the remote unit. The Other Asset Notice (1023) output on the remote device provides information on assets within Maintenance, including the last recorded status and location. This information will assist Maintenance Supply liaison verifiers in making timely and logical decisions relative to support of the requirement.

Exercises (235):

1. Why is all reparable item documentation routed through the reparable processing center or the reparable asset control center?

2. What two functions are combined under the reparable asset control center?

3. What role does Production Control play with respect to repair cycle assets?

4. What restriction is put on supply point stocks?

236. Define repair cycle assets and specify how they are used.

Repair Cycle Assets. The repair cycle asset concept of operation applies to all maintenance activities. Repair cycle assets are items with ERRC (equipment repair recoverability code) codes XD and XF. An AFTO Form 350 is required when the items require bench check and repair.

Production schedulers are responsible for scheduling and controlling repair cycle assets that are processed through supporting shops. The repair cycle program requires that Maintenance know the location and current condition of each DIFM item that was issued and that reparable items are scheduled for repair on an individual basis. The repair cycle asset concept outlined in this chapter places a great responsibility on Production Control schedulers.

The production scheduler must have sufficient data available to establish and maintain control of the in-shop workload. Production analysis will furnish job standards for use by Production Control in scheduling components for repair. Pending receipt of the reparable item, Production Control will establish and maintain a current DIFM suspense file consisting of DD Form 1348-1, copies 3 and 4, issues (ISU) and due-outs (DUO).

Each AFTO Form 350 will contain the hour and date the item was scheduled into the shop in the base repair cycle date block of Part II. This part of the form will be detached from Part I. The corresponding DIFM document number shown on DD Forms 1348-1 will be entered on AFTO Form 350, Part II.

The production controller and shop chief must follow through on each item scheduled into the shops to insure that they are processed as scheduled. When a production controller is not on duty, the shop chief will assume the above responsibility. Each change in the number of specialist personnel programmed for in-shop work and each change in the status of test benches, test stations, or test equipment that has an impact on shop scheduling will be immediately reported to the production scheduler by the shop chief.

When a serviceable asset is required, it will be requested through the supply expediter system. Exceptions to this policy are as follows:

a. Specialists may pick up items directly from the supply point. Supply point personnel will make out the issue document. Reparable items will be returned to Production Control or a reparable pickup point.

b. When a replacement item is not available from Supply and the end item is not mission capable supply (NMCS) or partially mission capable supply (PMCS), the specialist will remove the defective reparable item from the end item and deliver the reparable to Production Control for priority bench check, repair, and return to the work site. When any repair cycle asset is repaired without receiving a serviceable asset from Supply to satisfy the back order, a due-out cancellation must be requested. When requesting Supply to cancel the back order, a valid maintenance Action Taken Code and the net repair cycle days must be provided.

c. Documentation for assets repaired and returned with no back order established will be processed through Supply for repair cycle data update, using the turn around (TRN) repair cycle record update card (TO 00-20-3). The processing of a TRN provides the same demand data generation as if a serviceable asset had been issued from Supply and Maintenance had repaired and turned in the assembly that failed. Failure to process TRN data in a correct and timely manner results in reduced base stock levels and incomplete reports from which buy, repair, and distribution decisions are made by AFLC.

Exercises (236):

1. What are repair cycle assets?

2. What does Production Control use as a standard to estimate how long a task will take when scheduling items into the repair shop?

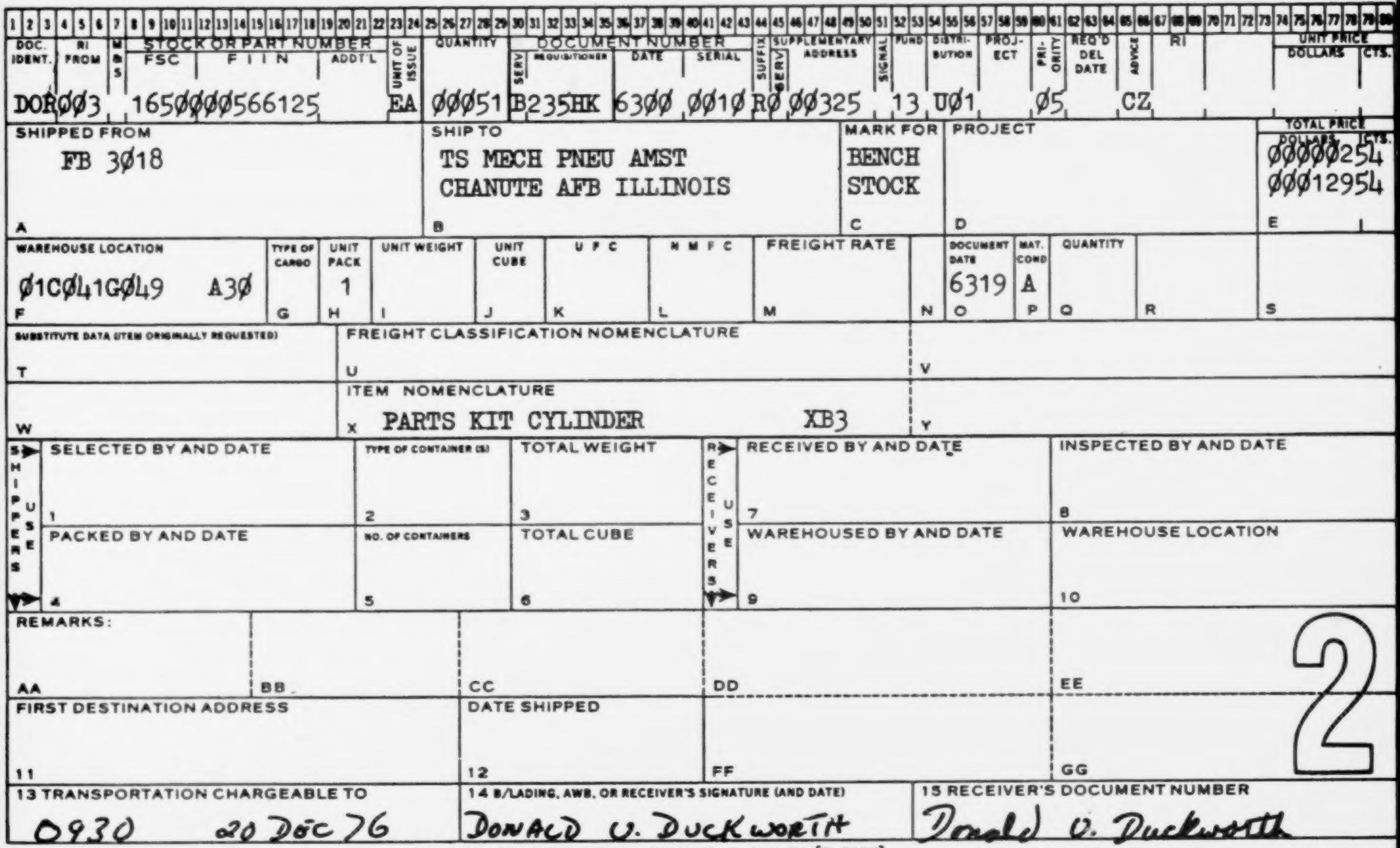
3. While the reparable item is in the shop for repair, what forms are maintained by the production scheduler?

4. What changes in the repair shop can have an impact on shop scheduling?

5. Briefly state the three exceptions to requesting serviceable assets through the supply expediter system.

237. Specify the procedures for repair cycle asset processing.

Repair Cycle Asset Processing. When a demand is made on the supply system, Supply will deliver the item to the specified delivery location. The individual receiving the item will sign and print his or her name on the DD Form 1348-1. The Supply representative will give copy 2 (fig. 2-6) to the individual receiving the item and deliver copies 3 and 4 to Production Control. All DIFM items must be returned to Supply as soon as they are repaired. All critical repair cycle items must be bench checked within 24 work hours to determine the appropriate repair action. If the item is NRTS code "1," it will be returned to Supply within 24 hours. If repair action is taken, Supply will be notified by Production Control of this action within 24 work hours after removal; then the item will be returned within 3 days. Items identified in the DIFM listing as critical and base/command intensively managed will be assigned maintenance repair



1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57 58 59 60 61 62 63 64 65 66 67 68 69 70 71 72 73 74 75 76 77 78 79 80

DOC. IDENT.: DOR
RI FROM: 003
M & S
STOCK OR PART NUMBER — FSC / FIIN / ADDT'L: 1650000566125
UNIT OF ISSUE: EA
QUANTITY: 00051
DOCUMENT NUMBER — SERV / REQUISITIONER: B235HK
DATE: 6300
SERIAL: 0010
SUFFIX: R
SERV / SUPPLEMENTARY ADDRESS: 0 00325
SIGNAL
FUND: 13
DISTRIBUTION: U01
PROJECT
PRIORITY: 05
REQ'D DEL DATE
ADVICE: CZ
RI
UNIT PRICE — DOLLARS / CTS.

SHIPPED FROM: FB 3018 — A
SHIP TO: TS MECH PNEU AMST
CHANUTE AFB ILLINOIS — B
MARK FOR: BENCH
STOCK — C
PROJECT — D
TOTAL PRICE — DOLLARS / CTS.: 00000254
00012954 — E

WAREHOUSE LOCATION: 01C041G049 A30 — F
TYPE OF CARGO — G
UNIT PACK: 1 — H
UNIT WEIGHT — I
UNIT CUBE — J
U F C — K
N M F C — L
FREIGHT RATE — M
N
DOCUMENT DATE: 6319 — O
MAT. COND: A — P
QUANTITY — Q
R
S

SUBSTITUTE DATA (ITEM ORIGINALLY REQUESTED) — T
FREIGHT CLASSIFICATION NOMENCLATURE — U
V
W
ITEM NOMENCLATURE — X: PARTS KIT CYLINDER XB3
Y

SHIPPERS USE
SELECTED BY AND DATE — 1
TYPE OF CONTAINER (S) — 2
TOTAL WEIGHT — 3
PACKED BY AND DATE — 4
NO. OF CONTAINERS — 5
TOTAL CUBE — 6

RECEIVERS USE
RECEIVED BY AND DATE — 7
INSPECTED BY AND DATE — 8
WAREHOUSED BY AND DATE — 9
WAREHOUSE LOCATION — 10

REMARKS:
AA
BB
CC
DD
EE
2

FIRST DESTINATION ADDRESS — 11
DATE SHIPPED — 12
FF
GG

13 TRANSPORTATION CHARGEABLE TO: 0930 20 DEC 76
14 B/LADING, AWB, OR RECEIVER'S SIGNATURE (AND DATE): DONALD U. DUCKWORTH
15 RECEIVER'S DOCUMENT NUMBER: Donald U. Duckworth

DD FORM 1348-1 (4 PART) 1 JAN 64
REPLACES DD FORM 1348-1 (UNIVAC), 1 JAN 64 [7 PART] WHICH WILL BE USED UNTIL EXHAUSTED.
DOD SINGLE LINE ITEM RELEASE/RECEIPT DOCUMENT

Figure 2-6. DD Form 1348-1.

priority 3. Other noncritical DIFM assets will be returned within 10 days. If the item cannot be repaired, the appropriate NRTS code will be documented on the AFTO Forms 349 and 350. Items NRTS coded will be promptly returned to Supply to insure early replenishment of stock levels.

Use the attached AFTO Form 350 to arrange the internal scheduling of reparable items. Production Control must insure that all required entries are correct. Part II of the AFTO Form 350 is retained by Production Control for scheduling purposes, and Part I accompanies the item (TO 00-20-3).

The Production Control scheduler assigns the work priority, places the item in AWM storage, and schedules the item for work into the shop. The shop is responsible for initiating the AFTO Form 349 and completing the AFTO Form 350 to document action taken, and for tagging the item when shop action is completed. The repair cycle asset and its documentation must be returned to Production Control for further action.

Each day before 1200 hours, the Production Control supervisor must review the suspense copies of DD Form 1348-1 (issue document) for items issued the previous day. If the reparable item has not been turned in for processing, the appropriate supervisor will be contacted to arrange for pickup. In addition, the Production Control supervisor will screen the DIFM Listing daily to insure that the location of each DIFM asset is known. When shops are located in a work area distant from Production Control, pickup and return may be accomplished on a scheduled basis.

Repair cycle assets returned from shops to Production Control in a serviceable, condemned, or NRTS condition will be processed for turn-in to the repair cycle support unit. Assets returned in AWP status will be processed as outlined in the next segment.

Exercises (237):

1. How do you receive items from the Supply representative?

2. What is the repair suspense time for critical NRTS code "1" items? For noncritical DIFM assets?

3. Briefly describe how the AFTO Form 350 is used in the repair cycle asset process.

4. Briefly describe the function of the Production Control supervisor.

238. State the method for processing items awaiting parts (AWP).

Processing Items Awaiting Parts. When a reparable item requires bits and pieces that are not available in bench stock, the shop will place a direct request on the demand processing unit. These requests may be processed on a "fill or kill". basis at the option of the major command. Verification of Urgency Justification Code (UJC) "AR" or "BR" requests will be performed by the requesting shop, unless the "fill or backorder" option is elected. If the fill or backorder option is used, verification of UJC "AR" and "BR" requirements will be met prior to submission by the requesting shop. When bits and pieces are requested, the requesting shop will advise the Production Control scheduler that the repair action is on a "hold for parts" and give the scheduler a new estimated repair completion time.

After processing issue requests, demand processing will notify the shop by telephone of the items not available. If the "fill or kill" option was used, the requester must verify for reinput by Supply or notify Production Control to perform verification and change the delivery destination code, if required. Shop personnel will then initiate two AFTO Forms 349 for the reparable item. The first AFTO Form 349 will be coded "C" (bench checked-repair deferred) in column D of the form. This form will be processed by the shop for maintenance data collection. Action taken code "C" will be entered in block 14 of the second AFTO Form 349, and this form will be forwarded along with the reparable item to Production Control. Shop personnel will forward the reparable DIFM end item and available bits and pieces from bench stock or partial issues along with the second copy of the AFTO Form 349 and AFTO Form 350, Part I, to Production Control.

When Production Control receives the necessary forms and the reparable item from the shop, the scheduler will update the corresponding AFTO Form 350, Part II, to indicate the date the item entered AWP status. The scheduler then forwards the item and the forms to the AWP monitor. The AWP monitor will insure that the AFTO Form 350, Part I, is properly attached to the reparable AWP asset and that the asset is properly secured while in AWP status. Production Control will also insure that the issue request for each bit and piece required, copies 3 and 4 of the DD Form 1348-1, and the AFTO Form 349 are filed with the AFTO Form 350, Part II, for the reparable AWP item.

When requisitioned bits and pieces have been ordered to repair an AWP item and they will not be available within the AWP holding time, the AWP monitor will submit a request to Supply for the status of the parts or for the next higher assembly, if sufficient time remains to submit another requisition. When the next higher assembly is a subassembly, the second requisition should be for this subassembly. Maintenance and Supply must monitor AWP closely and take positive action to insure that assets are returned to a serviceable condition. Necessary actions may include cannibalization, local purchase, supply difficulty letters, followups, and substitutions.

It must be emphasized that special efforts should be expended to obtain parts and perform authorized maintenance to preclude the necessity for returning AWP items to depot facilities. Items that are declared NRTS result in a higher cost for the Air Force as compared to items repaired at base level. The AWP holding time limit is designed to prevent holding a reparable item out of the repair cycle for long periods of time.

When all of the required bits and pieces are received, the AWP monitor will forward the reparable item, the bits and pieces, the AFTO Form 349, and the AFTO Form 350, Part I, to Production Control. Production Control will update the AFTO Forms 349 and 350 to indicate the number of days in AWP, schedule the work into the appropriate shop, and update the DIFM status to awaiting maintenance. Ideally, the production schedulers and AWP holding area should be collocated for immediate update of AWP status.

The responsibility for determining disposition action on AWP items rests with Supply. Supply will advise Production Control of status on AWP requisitions and NRTS actions. Under no circumstances will a Production Control scheduler assign NRTS code "4" to an AWP item without first making a followup with the appropriate shop or Supply to determine if the required bits and pieces have been received. When a final decision is made to return an AWP component to supply for lack of parts, the reparable item must be routed to the shop for preparation for turn-in. The Production Control scheduler will enter NRTS code "4" in column "D" of the AFTO Form 349, previously furnished by the shop, and in block 20 of the AFTO Form 350. Block 15 of the AFTO Form 350 will be stamped or signed by a shop production inspector. The AFTO Form 349 will be completed and forwarded to administration for MDC processing. The AFTO Form 350, along with two properly completed green tags, will accompany the component upon turn-in as prescribed in TO 00–20–2–10. Unused bits and pieces will be turned in to Supply or returned to the appropriate shop if authorized as bench stock. When the AWP monitor determines that bits and pieces have no base consumption or demand forecasted, they will be either installed in, packaged with, or attached to the item for return to Supply. Due-outs for bits and pieces not received will be cancelled.

Exercises (238):

1. If bits and pieces are not available in bench stock, what two options can be used to order parts?

2. After bits and pieces are ordered and verified, how will the AFTO Forms 349 be initiated for the AWP item?

3. What forms must the AWP monitor insure are on hand or attached to the AWP asset?

4. When requisitioned bits and pieces have been ordered to repair an AWP item and they will not be available within the AWP holding time, what action will the AWP monitor take?

5. What happens to items that exceed their AWP holding time limit?

6. Who determines if AWP items are to receive NRTS code "4" action?

7. When an AWP item goes NRTS code "4," what happens to the unused bits and pieces?

239. Name the technical order that covers materiel deficiency reporting (MDR), state the purpose of the MDR system, and define the two categories of MDR reports.

Materiel Deficiency Reporting (MDR). The procedures for MDR are outlined in technical order 00–35D–54. TO 00–35D–54 states that the purpose of MDR is to establish a system that feeds back deficiency data on hardware and computer programs to activities responsible for development, procurement, and other logistics management functions so that action can be initiated to correct and prevent maintenance materiel, design, and quality deficiencies. A maintenance deficiency is an unfavorable characteristic of an item which impedes maintenance operations and results in the use of excessive maintenance man-hours. Primary factors to be considered are reliability, accessibility, simplicity, supportability, standardization, and interchangeability. Examples of maintenance deficiencies are unsatisfactory access to areas requiring inspection, servicing, replacement, and repair; inadequate interchangeability of parts; and high rate of nonavailable special tools, test equipment, and facilities required for scheduled and unscheduled maintenance. A design deficiency is any condition that limits or prevents the use of materiel for the purpose intended or required where the materiel meets all other specifications or requirements. These deficiencies cannot be corrected except through a design change. A quality deficiency is any deficiency (e.g., physical, chemical, electrical, functional) noted in materiel which is attributable to nonconformance to applicable specifications, drawings, standards, technical orders, or workmanship during manufacture, repair, modification, or maintenance.

Category I MDR. The Category I MDR is a report of an emergency condition on all types of equipment, systems, and computer programs that presents, or has the clear potential to present, an unacceptable safety, operational, or maintenance hazard. These conditions include accidents or incidents that do damage to persons or property and that are not caused by enemy action. When a mishap is classified as an incident and the causes are limited to materiel deficiencies, a combined Incident—Category I MDR will be submitted as a joint effort of the Deputy Commander for Maintenance and the Safety Office.

Materiel, computer program, or installation deficiencies that require the affected equipment be withheld from use will be reported as Category I MDR. A critical deficiency on electronic or electrical equipment is any malfunction or design deficiency (including safety devices) that could result in exposure of maintenance or operating personnel to lethal voltages, excessive radiation, or other potential danger by either direct or indirect action.

Category II MDR. The Category II MDR is a report of quality deficiencies in materiel that are attributable to nonconformance to applicable specifications, drawings, standards, technical orders, or workmanship during manufacture, repair, modification, or maintenance.

It is a report of design and maintenance materiel deficiencies on work unit coded (WUC) items on new weapon systems and equipment for which insufficient Maintenance Data Collection (MDC) System historical data exists. For established weapon systems, it is a report of deficiencies that have a serious adverse impact on mission capability and have been identified through the MDC System. Screening points will identify candidates to be reported under these criteria to their major command headquarters. Reporting on these items will be agreed upon by the major command headquarters and the ALC involved prior to implementation.

And, finally, it is a report of design and maintenance materiel deficiencies on non-work-unit-coded (WUC) items (i.e., items that would be listed as "not otherwise coded" in the –06 manual or items not listed in an –06 manual) that do not have a safety impact, but the uncorrected existence of which would through prolonged usage:

a. Have a negative effect on operational efficiency.

b. Reduce tactical effectiveness or tactical support capability.

c. Reduce operational life or general service utilization of equipment.

d. Create economic burdens (manpower and money).

Exercises (239):

1. What technical order outlines the procedures for materiel deficiency reporting (MDR)?

2. State the purpose of the MDR System.

3. Briefly define Category I and II MDR reports.

240. *State procedures for reporting Category I and II MDR reports.*

Method of Reporting Materiel Deficiencies. Materiel deficiency reporting (MDR) begins with you (originating point), the person who discovers the deficiency. After you have gathered all the information in draft form needed for the report, the next step in the process is to take this information to the screening point.

The Quality Control (QC) staff of the Deputy Commander for Maintenance (Category I and II MDRs) and the Chief of Safety (Category I MDR) of the submitting activity are the screening points for MDRs, and they will review all MDRs prior to submittal to insure that they are reported under the correct method and are routed correctly. Emphasis will be placed on identification of materiel deficiencies that will be the subject of Category I MDRs to insure that only truly hazardous conditions are reported as Category I. Quality Control will prepare your MDR on DD Form 173, Joint Messageform, assign a report control number to your MDR, record the control number on AF Form 2423, Technical Order Improvement or Materiel Deficiency Reports Log, and submit the MDR by electrical transmission to the proper action point (the activity responsible for resolution of your reported deficiency).

The action point that is responsible for resolving your MDR informs you of action taken or proposed through your Quality Control Office.

Category I MDR. The category I MDR will be prepared on DD Form 173 using the format shown in table 2-13. Although this table is for Category II MDR report, the only difference is the subject, in which Category I is substituted for Category II. The MDR is submitted by message with an assigned precedence of priority within 72 hours after discovery of the deficiency. The subject of the message should be "Category I Materiel Deficiency Report."

Category I MDRs are submitted on materiel or installation deficiencies that are known or suspected to be causes in Air Force mishaps (AFR 127–, *Investigating and Reporting US Air Force Mishaps)*. Mishap-related Category I MDRs must reference the mishap control number assigned by the submitting safety office in the Report Type block of the MDR. This reporting requirement excludes those conditions which meet the criteria for the Incident—Category I MDR prescribed in the following paragraph.

The Incident—Category I MDR is prepared on a DD Form 173 using the format similar to table 2-13, with the following exceptions: Subject is changed to Incident—Category I MDR. No. 18 is broken down to cost in man-hours and material, and No. 22 is changed to cover different items. The combined format MDR is submitted by message with an assigned precedence of priority in accordance with the reporting schedule prescribed in AFR 127–4. All entries for the Category I MDR, the Incident—Category I MDR, and the Dull Sword—Category I MDR will be coded with an item number, commencing with item three, and the description of the entry. If an entry is not applicable to the deficiency being reported, enter NA.

Category II MDR. The Category II MDR is prepared on a DD Form 173 using the format prescribed in table 2-13. *The MDR is submitted by message, with an assigned* precedence of routine, within 15 work days after discovery of the deficiency. The subject of the message should be "Category II Materiel Deficiency Report." All entries for the Category II MDR must be coded with an item number, commencing with items three and four and the description of the entry. If an entry is not applicable to the deficiency being reported, enter NA.

Exercises (240):

1. Explain the following steps of MDR reporting:
   a. Originating point.
   b. Screening points.
   c. Action point.
2. What are the screening points for a Category I MDR? A Category II MDR?
3. What are the steps QC performs in preparing your MDR?
4. How soon must your MDR be submitted following the discovery of the deficiency?

241. State procedures for processing MDR exhibits.

Processing MDR Exhibits. The term "MDR exhibit" applies to any deficient items of hardware or computer program in support of MDRs which are submitted in accordance with TO 00–35D–54. Pending shipment, MDR exhibits are held by Quality Control (or Base Supply, when storage facilities are not available) or as designated by the major command in a secure, minimum access (preferably locked) area, to insure that the exhibit is not altered or lost. The screening point enters the address of the MDR exhibit holding activity under Other Pertinent Data, item No. 22K of Table 2-13. The MDR exhibits are shipped by priority methods in accordance with AFM 67–1. A bench check is accomplished by field activities only to the extent of determining that the item is deficient. When an MDR exhibit is not available, enter in the Action Or Disposition item (Table 2-13, item No. 21) of the MDR the nature of the action taken, and identify the circumstances leading to the action.

Normally, MDR exhibits should not be tampered with in any way; no attempt should be made to repair them. But, where your unit has already established the capability to repair a particular item, then it may be repaired. Even then, the deficiency should be reported. When directed, forward the item to the action point or support point (the activity that assists the action point in processing and resolving a deficiency) in the exact condition as it was when found deficient. Field activities will not ship or hand-carry exhibits prior to receipt of disposition instructions.

Forms required. Complete the AFTO Form 349 with the action taken code "C" when the exhibit is held awaiting disposition instructions. Complete an AFTO Form 349 with the action taken code "8" when the exhibit is shipped to an action or support point for examination.

Identify all the exhibits with an AFTO Form 114, Materiel Deficiency Exhibit. The AFTO Form 114 is shown in figure 2-7 and the blocks are self-explanatory, with the exception of blocks 6 and 8. The reverse side of the form is not shown; it contains block 6 (Remarks Continued), block 7 (Date Released), and block 8 (Released To). In block 6, Remarks, enter information that was not included in other blocks and that will assist in identifying the exhibits. Mark "Critical Item" in this block if the item is a critical supply asset. In block 8, Released To, enter the name of the activity to which the exhibit was released, such as the ALC office symbol, telephone extension, and technician's name at the requesting point.

Securely attach an AFTO Form 114 to the exhibit and also to the outside of the container near the address label. Place one information copy of the MDR in an envelope and securely attach the envelope to the AFTO Form 114 on the exhibit if the MDR is unclassified. When the report is classified, handle it in accordance with applicable security directives. The AFTO Form 114 is detached from the exhibit when it has served its purpose and the item is processed in accordance with its condition.

DD Form 1575, Suspended Tag—Materiel, is condition coded "Q" before you ship the exhibit. If the computer at your base will not accept condition code "Q," you should use "J". (See our illustration of the DD Form 1575 (Brown Tag) in Chapter 1; this is in accordance with TO 00–35D–54.

Screening point. The screening point (Quality Control) at the originating activity (your base) will advise the action point, the item manager, the support point (when designated by the action point), and the using command headquarters, by message, of the date, document number, and method of shipment of all MDR exhibits.

MDR exhibits are held by QC, Supply, or another command designated activity until disposition instructions

TABLE 2-13
CATEGORY II MDR FORMAT

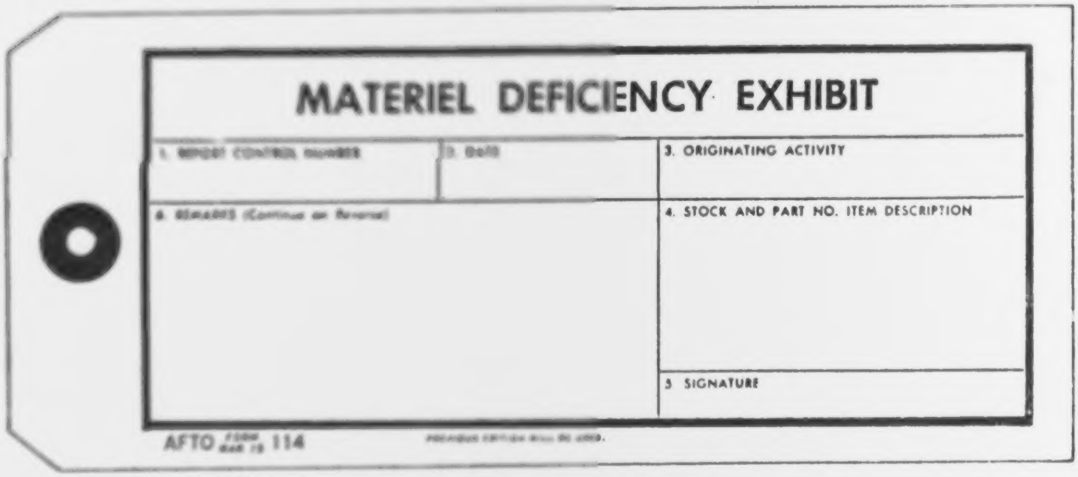
GENERAL: Category II MDRs will be prepared on DD FORM 173 with an assigned precedence of routine in the format shown below. The item number and description of each line entry will *be entered on all MDRs* commencing with item 3. If the entry is not applicable to the deficiency being reported, enter N/A. The information required in Block 22 is coded using alpha codes a through m.

FM: (Screening point)
TO: (Maintenance engineering manager)
INFO: (As required)
SUBJECT: Category II Materiel Deficiency Report

3. RCN: (Report Control Number)
4. D Def DISC: (Date Deficiency Discovered)
5. NSN: (National Stock Number)
6. NOM: (Nomenclature)
7. MFR, SHIPPER, OVHL: (Manufacturer, Manufacturer's Code, Shipper, Source of Repair or Overhaul)
8. MFR PN: (Manufacturer's Part Number)
9. SER, LOT, BATCH NR: (Serial, Lot, Batch Number)
10. CONTR, PO, DOC NR: (Contract, Purchase Order, Document Number)
11. NEW OR OVHL: (Item New or Overhauled)
12. D MFD OR OVHL: (Date Manufactured, Repaired or Overhauled)
13. OTF: (Operating Time at Failure)
14. GFP: (Government Furnished Property)
15. QTY: (Quantity)
    - a. RECD: (Received)
    - b. INSPD: (Inspected)
    - c. DEF: (Deficient)
    - d. IN STK: (In Stock)
16. DEF ITEM WORKS ON OR WITH: (Deficient Item Works on or With)
    - a. END ITEM: (Self-explanatory)
    - b. NHA: (Next Higher Assembly)
17. DOL VAL: (Dollar Value)
18. EST COR COST: (Estimate Correction Cost)

19 ITEM UNDER WARRANTY: (Self-explanatory)

20. WUC: (Work Unit Code)
21. ACT OR DISP: (Action or Disposition)
22. DETAILS:
    - a. CIR PRIOR TO DIEF: (Circumstances Prior to Difficulty)
    - b. DESC AND CAUSE OF DIFF: (Description and Cause of Difficulty)
    - c. ACT TAKEN OR RECM: (Action Taken and/or Recommended)
    - d. AERNO: (Aeronautical Equipment Reference Number)
    - e. TECH DATA DEF: (Technical Data Deficiency)
    - f. SUPPORT DATA MAILED: (Self-explanatory)
    - g. REPORT TYPE: (Self-explanatory)
    - h. SM OR IM ALC CODE: (System Manager or Item Manager ALC Code)
    - i. SRD: (Standard Reporting Designator)
    - j. CMD CODE: (Command Code)
    - k. OTHER PERTINENT DATA:
        - (1) MDR EXH HOLD ACT: (MDR Exhibit Holding Activity)
        - (2) PHOTO SUP: (Photographic Supplies)
        - (3) PERT DATA: (Pertinent Data)
    - l. COGN OFF: (Cognizant Official)
    - m. CERT OFF: (Certifying Official)



MATERIEL DEFICIENCY EXHIBIT

1. REPORT CONTROL NUMBER
2. DATE
3. ORIGINATING ACTIVITY
6. REMARKS (Continue on Reverse)
4. STOCK AND PART NO. ITEM DESCRIPTION
5. SIGNATURE

AFTO FORM 114 — PREVIOUS EDITION WILL BE USED.

Figure 2-7. AFTO Form 114.

are received or for a period of time not to exceed 25 workdays. Interim disposition instructions from the action point, such as "hold the MDR exhibit pending further instructions," are regarded as a disposition instruction. Starting time for the holding period will begin at the date that the specific MDR is approved and forwarded by the screening point. If interim or final disposition instructions are not received at the screening point in 20 workdays, follow-up action will be initiated by the screening point. When disposition instructions are not received within the prescribed time limit or when the action point advises that the asset is not required as an MDR exhibit, the item will be processed in accordance with its condition, i.e., serviceable, reparable, condemned, etc. When this situation occurs, the item is no longer categorized as an "MDR Exhibit"; the AFTO Form 114 will be detached and destroyed. Reparable assets are processed in accordance with TO 00-20-3 and AFM 67-1, Volume I.

Special handling is used for critical items as prescribed in AFM 67-1, Volume I, and for engines that are the subjects of MDRs to assure that they are shipped quickly when required; or, if they are not needed as MDR exhibits, they are processed in a minimum amount of time to alleviate spares shortage. When new procurement items code "XB" are found deficient, hold all like-deficient items pending disposition instructions. Indicate the hold action on the MDR involved. All documents submitted to the action or support point will indicate "Critical Item," as appropriate.

Use of photographs. Support data (such as photographs or drawings) and copies of supporting documents (such as AFTO Form 350 and DD Forms 1574 and 1577-2) are of great assistance to action or support points and will be provided in sufficient detail to completely document the reported discrepancy. They will accompany the MDRs submitted by mail; they are to follow Category I MDRs at the earliest possible date. Good photographs and documentation often may be substituted for exhibits, saving both time and money. The screening point will contact the appropriate Air Logistics Center (ALC) to determine when photographs may be substituted for MDR exhibits. Photographs, both close-up detail and distant, showing complete should area failure, should be made when photographic facilities permit. One information copy of the MDR should be attached to the photograph.

Each photograph should be marked on the face with identifying and orienting lines, such as aircraft, missile or space vehicle, TMS and serial number, and station numbers and locations so that the exact location and nature of the reported condition will be clearly shown. When possible, these markings will be placed on the affected part or adjacent structure prior to photographing. The back of each photograph will be annotated with the MDR number and, if applicable, the mishap control number. Three prints of each photograph or one duplicate negative will be forwarded to the appropriate action point or the support point when designated by the action point.

MDRs submitted are subject to appropriate security classification transmission procedures under applicable security directives. Caution is required when various elements of maintenance data are involved to assure that the appropriate security classification is determined in accordance with the policy and procedures outlined in the applicable security directives.

Exercises (241):

1. What agency holds an MDR exhibit pending shipment?

2. Can you bench check, disassemble, or repair an MDR exhibit? Explain.

3. What form is used to identify MDR exhibits? Explain the block 6 (Remarks) entry.

4. Briefly explain the time limitations on holding MDR exhibits.

5. Why are photographs often substituted for an MDR exhibit?

6. Who determines if photographs may be substituted for the MDR exhibit?

2-4. AFTO Form 781 Series.

The Air Force maintains documentation to make certain that its equipment is in proper operational condition and to determine if any additional requirements exist. In this section, we will discuss the forms the Air Force uses to obtain this assurance for aircraft, the AFTO Form 781 series.

242. State the purpose of AFTO Form 781 series forms, and identify them by number.

Purpose of Forms in the 781 Series. The forms contained in this series are used collectively to provide maintenance, inspection, status, and flight records for the particular aircraft for which they are maintained. A single binder contains the applicable series forms for a given trainer in a specified sequence. This sequence will be determined by command directive or as supplemented by local authority. The following is a list of the AFTO Form 781 series that generally apply to aircraft. This list also includes the purpose of each form.

AFTO Form 781F, Aerospace Vehicle Flight Report and Maintenance Document. This form serves as an identification cover sheet for the binder being maintained.

AFTO Form 781G, General Mission Classification—Mission Symbols. This form contains basic information to aid in making entries on the AFTO Form 781 series.

AFTO Form 781M, System Numbers General Grouping and System Titles. This form is a continuation sheet for the AFTO Form 781G described above.

AFTO Form 781H, Aerospace Vehicle Flight Status and Maintenance Document. This form is used to document maintenance status and show the status and history of inspections that are specifically related to the daily flying activity or specific day involved.

AFTO Form 781A, Maintenance Discrepancy and Work Document. This form is used to document each discrepancy discovered by the pilot, operator, or maintenance personnel.

AFTO Form 781K, Aerospace Vehicle Inspection, Engine Data, Calendar Item Inspection, and Delayed Discrepancy Document. This form provides a record of inspections (other than daily or preflight), TCTOs, and delayed discrepancies.

Exercises (242):

1. What is the number of the AFTO Form 781 series that is used by pilot, operator, or maintenance personnel to document discrepancies?

2. State the purpose of the AFTO Form 781H.

3. State the purpose of the AFTO Form 781K.

243. State the meanings of status symbols used in the AFTO Form 781 series forms.

Status Symbols and Their Use. The symbols we will describe are established for use on the AFTO Form 781 series forms to make important notations instantly apparent. They indicate the mechanical condition; the fitness for flight or operation; or the servicing, inspection, or maintenance status of an aircrew training device. The red X, circled red X, red dash, and red diagonal are the symbols that you will use. You must fully understand the use of these symbols in order to make the proper entries.

Red X. The red X indicates that the aircraft or equipment is considered unsafe or unfit for flight or use. When you enter this symbol, you are indicating that the equipment cannot be flown or used until the unsafe or unfit condition is corrected. Furthermore, no one will authorize the equipment to be used until the red X symbol is properly cleared. While performing your normal duties, you must use a red X symbol under any of the following conditions:

a. Immediately upon discovery of an unsatisfactory condition that is serious enough to warrant its use.

b. Upon removal of any component or assembly that affects the safe operation of the equipment.

c. When a scheduled inspection is in progress, excluding preflight or daily inspections.

d. When you install a "jump wire" or other type of shorting device in an electrical system while performing maintenance.

e. Any time a pitot or static system line or drain is open, thus rendering the system inoperative. Sealing the pitot tube or covering the static ports also makes the system inoperative; therefore, a red X must be entered in the forms.

Under certain conditions, red X symbols are required for TCTOs. The following conditions are:

a. Upon receipt of an immediate action TCTO.

b. When a routine action TCTO is within 60 days of its rescission date.

After you have corrected the condition that caused the red X, sign only the CORRECTED BY block of the AFTO Form 781A. The minimum maintenance signature is first name, initial, last name, and grade. An inspection of the work you performed to correct the discrepancy and an audit of all related documentation that you made is performed by a maintenance technician or supervisor. This technician or supervisor must be authorized, in accordance with AFR 66–1, to clear a red X symbol. The initial over the red X symbol and the signature in the INSPECTED BY block in the AFTO Form 781 indicates that a highly qualified technician has completed these actions.

Circled red X. A red X inside a red circle will be entered to indicate that the equipment is grounded pending compliance with an urgent action TCTO. Enter this symbol at the time of starting the TCTO. A red X may be required if the condition meets the requirement for a red X. The circled red X requires the same sign-off and inspection procedures as does the red X.

Red dash. If you find that a scheduled or special inspection, time change item replacement, or operational check is due and has not been completed, you must indicate this condition by using the red dash symbol. This symbol indicates that the condition of the aircraft is not known and a more serious condition may exist. That is why you should take action to quickly correct the red dash condition. When you are performing inspection requirements and find that time change items are nearing their replacement date, enter the red dash symbol in the forms to show that these items are due. This symbol is cleared by entering the initial of your last name in black over the symbol. This is done only after you have completed the action that was past due.

Red diagonal. Use the red diagonal symbol to indicate that you have found an unsatisfactory condition on the equipment that is not sufficiently serious to warrant that it be withdrawn from use. This symbol is also used to indicate receipt of an urgent action TCTO or a Category I, routine action, safety modification TCTO. Sign-off procedures are the same as for the red dash. The red diagonal or any red symbol, once entered, can never be erased even if entered in error, so exercise care when using these symbols.

Exercises (243):

1. During a daily inspection you found that, as soon as the master power switch was turned on, the main transformer began smoking. You shut off all power to the equipment to prevent further damage. What symbol would best describe this condition?

2. What does a circled red X mean?

3. What symbol indicates that a special inspection is past due?

4. What does the red diagonal symbol mean?

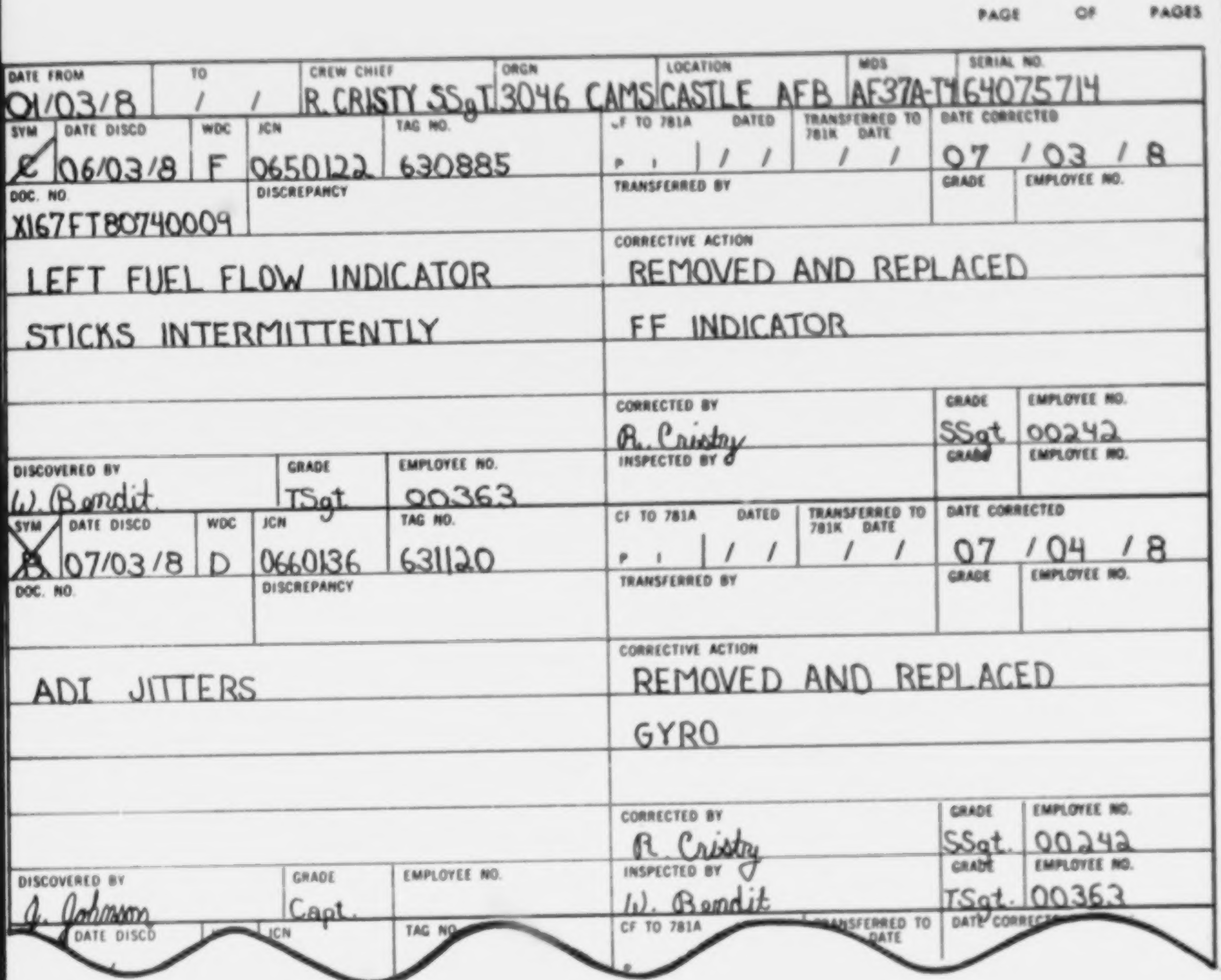
244. Given various maintenance situations, state the proper entry(s) on the AFTO Form 781A.

Block Entries for AFTO Form 781A. You do not make any entries on the AFTO Form 781G and 781M, as they only provide guidance to aid you and aircrewmembers in completing or interpreting entries on the rest of the series. The cover sheet, AFTO Form 781F, is a one-time form that can be completed by referring to TO 00–20–5. During the following discussion, we will describe specific entries you will make on the AFTO Form 781A.

Look at the AFTO Form 781A shown in figure 2-8; the actual form is printed identically on both sides. The AFTO Form 781A is sectioned off to record discrepancies and corrective actions relative to the maintenance of aircraft. Two examples of proper entries are shown in figure 2-8. The first is a minor discrepancy; thus, the red diagonal is entered in the SYM block. The date discovered in the DATE DISCD is self-explanatory. The when discovered code from the work unit code manual is entered in the WDC block. (Code F, shown in fig. 2-8, indicates discovery during unscheduled maintenance). In the DISCREPANCY block, the discrepancy (left fuel flow indicator sticks intermittently) is entered, and the name and employee number of the individual discovering the discrepancy are entered in the DISCOVERED BY block and EMPLOYEE NO. block respectively. Similar entries could well have been made by the pilot for a problem found during operation of the equipment or, as in this case, by a maintenance technician who discovered the problem while performing other maintenance.

If you were assigned the task of clearing this writeup, you would be required to complete some additional documentation on this form. To clear the discrepancy, you had to replace the indicator; thus, you would indicate this in the CORRECTIVE ACTION block. You would then enter, in the TAG NO block, the number of the AFTO Form 350 tag that you had attached to the old indicator. Also, you would put the supply document number for the new indicator in the DN block. (If a part is ordered, immediately enter the document number in the DN block even if the corrective action is deferred to a later time.) The corrective action is complete when you sign the CORRECTED BY block with your minimum maintenance signature (first name initial, last name, and grade), enter the date corrected, and employee number and place your last name initial over the red diagonal in the SYM block.

The second example in figure 2-8 shows a red X that caused downtime (the trainer could not be used or the aircraft could not be flown). The documentation is similar;



PAGE OF PAGES

DATE FROM: 01/03/8
TO: / /
CREW CHIEF: R. CRISTY SSgT
ORGN: 3046 CAMS
LOCATION: CASTLE AFB
MDS: AF37A-T4
SERIAL NO.: 64075714

SYM: /
DATE DISCD: 06/03/8
WDC: F
JCN: 0650122
TAG NO.: 630885
CF TO 781A: P I
DATED: / /
TRANSFERRED TO 781K DATE: / /
DATE CORRECTED: 07 / 03 / 8
DOC. NO.: X167FT80740009
TRANSFERRED BY:
GRADE:
EMPLOYEE NO.:
DISCREPANCY: LEFT FUEL FLOW INDICATOR STICKS INTERMITTENTLY
CORRECTIVE ACTION: REMOVED AND REPLACED FF INDICATOR
CORRECTED BY: R. Cristy
GRADE: SSgt
EMPLOYEE NO.: 00242
INSPECTED BY:
GRADE:
EMPLOYEE NO.:
DISCOVERED BY: W. Bandit
GRADE: TSgt
EMPLOYEE NO.: 00363

SYM: X
DATE DISCD: 07/03/8
WDC: D
JCN: 0660136
TAG NO.: 631120
CF TO 781A: P I
DATED: / /
TRANSFERRED TO 781K DATE: / /
DATE CORRECTED: 07 / 04 / 8
DOC. NO.:
TRANSFERRED BY:
GRADE:
EMPLOYEE NO.:
DISCREPANCY: ADI JITTERS
CORRECTIVE ACTION: REMOVED AND REPLACED GYRO
CORRECTED BY: R. Cristy
GRADE: SSgt.
EMPLOYEE NO.: 00242
INSPECTED BY: W. Bandit
GRADE: TSgt.
EMPLOYEE NO.: 00363
DISCOVERED BY: J. Johnson
GRADE: Capt.
EMPLOYEE NO.:

DATE DISCD
JCN
TAG NO
CF TO 781A
P
TRANSFERRED TO DATE
DATE CORREC

Figure 2-8. AFTO Form 781A, Maintenance Discrepancy and Work Document.

however, the red X symbol can only be cleared by authorized personnel. The authorized inspecting individual verifies that the problem was fixed and all required maintenance was properly done as per TO instructions and that close attention was paid to every minor detail. Only when sure that everything is correct, the inspecting individual places the minimum maintenance signature and employee number in the INSPECTED BY block and the last name initial over the red X symbol in the SYM box.

Any one who discovers a problem on an aircraft should write it up on the aircraft's AFTO Form 781A. If you think the aircraft should not be flown or the equipment should not be used until the problem is corrected, you should put a red X in the SYM block. By doing so, you insure that a qualified 7-level technician who is responsible for that equipment will see that the problem is corrected.

If you feel that a previously entered discrepancy is more serious than originally thought, then you can change the red diagonal to a red X. If you do so, you must draw a single line through the name of the person who made the original entry and, immediately above it, write in your own maintenance signature and employee number.

You cannot change a red X to a red diagonal. This requires special handling in accordance with TO 00–20–5.

Exercises (244):

1. What is the purpose of the AFTO Form 781A?

2. If the attitude indicator that you had ordered went on back order, what entry should you make on the AFTD Form 781A?

3. If you cleared a red X discrepancy, what entries should you make of the AFTO Form 781A?

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CHAPTER 3

Maintenance Management

THIS CHAPTER is designed to introduce you to the Air Force concepts of maintenance management and organizational structure. We will discuss the preparation of organizational and functional charts to give you a better idea of how we fit into the overall maintenance complex. We will also discuss the duties of the Deputy Commander for Maintenance under AFR 66–1 and AFR 66–5 and explore the differences between the two maintenance concepts. We will outline basic parts of the maintenance and inspection systems used in the Air Force today.

3-1. Maintenance Management

Maintenance, a functional element of any Air Force organization, is responsible for insuring that Air Force material is serviceable, safe to operate, and properly set up to meet the mission needs. This is done by performing tasks which include inspection, repair, overhaul, modification, preservation, testing, and condition or performance analysis. These jobs are done on a set schedule when possible.

245. Differentiate between the maintenance management policies of AFR 66–1 and AFR 66–5.

AFR 66–1, Maintenance Management. The traditional centralized maintenance concept outlined in AFR 66–1 is based on specialization of personnel. It is intended to provide the management procedures needed to insure the most effective use of assigned personnel within their occupational specialty. The focal point of this maintenance concept is the Deputy Commander for Maintenance (DCM). The DCM staff does the planning, scheduling, assigning of priorities, and dispatching and controlling of work, as well as the selecting of skills needed for the job.

AFR 66–5, Production Oriented Maintenance Organization. On the other hand, the production oriented maintenance organization (POMO) concept, as outlined in AFR 66–5, is designed to meet the peculiar combat needs of the tactical air forces. The different locations, aircraft, and types of missions require a complete reorganization of people and the decentralization of decisionmaking to the lowest practical level. This approach to decisionmaking permits supervisors to deviate from the traditional specialization of personnel and use available airmen for any job they are capable of handling.

Exercises (245):

1. Name the Air Force regulations which outline each of the maintenance management procedures.

2. In which maintenance management concept is the DCM the decisionmaking authority?

3. What is the purpose of the POMO maintenance concept?

4. Why do the tactical air forces need to decentralize decisionmaking to the lowest practical level?

5. How does the decentralization of decisionmaking to the lowest practical level help aircraft maintenance managers get the job done?

246. Identify duty sections and procedures which insure good, reliable repairs in aircraft maintenance.

Quality of Maintenance. Both concepts of maintenance rely upon quality maintenance. The Quality control (QC) section of AFR 66–1 and the Quality assurance program (QAP) of AFR 66–5 are designed to improve technician competence and maintenance quality. Their common objectives are realized by training airmen to use standard maintenance practices and to strictly comply with technical data, and by periodically evaluating their people and hardware with highly qualified technicians.

Quality control and other inspection reports are valuable management tools which must be given proper attention.

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Positive action is required to fix the specific defects identified in the reports and eliminate their causes. Each of us should be aware of our own deficiencies and those of our units. More important, we should do our best to correct those defects and eliminate their causes.

Exercises (246):

1. Which duty section of each maintenance concept enforces quality maintenance?

2. What is the purpose of quality control, quality assurance, and other inspection reports?

247. Identify factors affecting maintenance capability.

Before we get into maintenance capability, we need to understand terms such as sortie, sortie rates, and aircraft generation. A sortie is a flight of an aircraft, and a sortie rate is the number of flights by a unit in a given amount of time. Aircraft generation is the preparation of aircraft for flight.

Maintenance Capability. Maintenance capability is the ability of a unit to keep its assigned aircraft and equipment in serviceable condition and proper configuration. This capability is determined from available resources of personnel, their skill levels and experience, and equipment and its condition. Because all personnel need rest, the number of productive hours available to managers is limited; therefore, every effort is made in maintenance plans and schedules to insure that each person is productively used throughout each shift to keep the assigned aircraft and equipment in good condition. Skill levels are distributed among the shifts to provide the best mission support, supervision, and training. During periods of increased readiness, high sortie rates, or aircraft generation, maintenance personnel must be used for direct mission support, not assigned to base details.

When we voluntarily joined the Air Force and accepted the training, pay, and benefits of the group, each of us took on the obligation to support the Air Force. This meant that we would normally work 8 hours a day, 5 days a week; but we are obligated 24 hours a day. When necessary, we can be tasked to extend our unit's maintenance capability by working 12 hours each and every day. Under unusual circumstances (remote duty locations), we may have to work 16 hours with a 12-hour rest period.

Exercises (247):

1. You are told, "Tomorrow's sortie rate is beyond this unit's generation capability." Explain, in simple terms, what you have been told.

2. What factors determine a unit's maintenance capability?

3. During periods when the workload is very heavy but the circumstances are not unusual, how many hours may your boss require you to work before giving you an extended rest period?

4. When may you have to work 16 hours with a 12-hour rest period between each 16-hour work period?

248. State basic requirements for maintenance accomplishment.

Equipment Maintenance. Equipment maintenance is made up of two basic elements, the technical element of maintenance engineering and the maintenance production element. At the operating level, we are concerned primarily with maintenance production and providing data inputs for maintenance engineering decisions. Maintenance production is the actual performance of equipment maintenance and related acts such as servicing, repairing, testing, overhauling, modifying, calibrating, inspecting, and configuring.

Your squadron commander is the key person in using squadron resources to meet mission requirements. He or she must work closely with the DCM to understand the requirements, capabilities, responsibilities, and accomplishments of the maintenance activities. The squadron commander must demand professional and quality maintenance and strict adherence to technical orders, which are military orders issued under the authority of the Secretary of the Air Force. This includes accurate recording and reporting so that documents and reports show existing conditions.

As organizations grow, the distance between the worker (you) and the commander increases. Maintenance officers and noncommissioned officers (NCOs) fill the gap. In addition to their duties as technical managers, they are specifically responsible for the welfare and discipline of their people.

Exercises (248):

1. Which element of equipment maintenance provides information for the other one to make engineering decisions?

2. What is maintenance production?

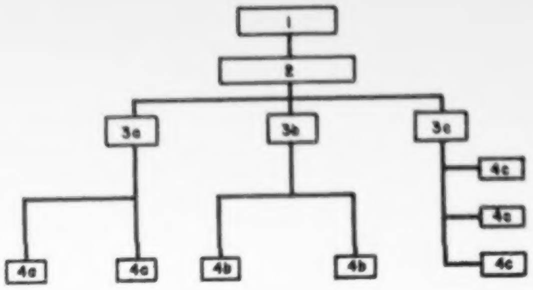


Figure 3–1. Organizational chart.

3. What must a squadron commander demand of assigned maintenance personnel who are working on Air Force equipment?

4. In large organizations, who helps the squadron commander obtain professional quality maintenance, strict adherence to TOs, and accurate maintenance and reporting from personnel.

3-2. Organizational Structure of Maintenance Complexes

Organizational structures vary because of differences in mission, equipment, location, size, etc. For example, the organizational elements that make up the deputy commander for maintenance (DCM) organization may be organized as sections or branches. Certain functional elements are necessary in all maintenance complexes, however. These functional elements provide for delegation of authority to insure efficient management of the maintenance complex.

One of the best ways to show the structure of an organization is through the use of organizational/functional charts. We will explain a few features of these charts and use them to take a closer look at the maintenance organization.

249. State the use of an organizational chart; indicate correct placements and sizes for selected elements in an organizational chart; and identify errors, elements, and relationships in charts.

The purpose of the Air Force command structure is to make it possible for such a huge organization to accomplish its mission most effectively. Every person in the Air Force has a job to do, and it must be done adequately if the Air Force is to succeed. This applies from the airman basic to the Air Force Chief of Staff. To clarify more specifically where you fit into your unit, to whom you are responsible, and those responsible to you, we shall discuss the organizational and functional charts. Some of the basic rules involved in the construction of these charts are presented below.

Rules for Organizational Chart Construction. Policies of the Air Force organization, along with local regulations, are overriding considerations in organizational chart construction. Refer to figure 3-1 as we discuss the basic rules for chart construction.

(1) Inclose all applicable organization names in boxes, such as rectangles or squares.

(2) Show one level above and two levels below the primary organization or position being charted. Make sure that the main position in each level—especially the uppermost level—is clearly recognizable as the most prominent.

(3) Use a rectangular box to represent each unit or position on a chart.

(4) Use straight, solid lines to show the lines of command or authority.

(5) Use the shortest possible connecting lines. Avoid diagonal lines, curved lines, and unnecessary angles.

(6) The rectangle which represents the position or unit around which the chart centers should be the largest one on the chart. Rectangles above and below the key figure should be smaller. Make the boxes for each successive lower level narrower.

(7) Rectangles on the same organizational level should be of equal size and on the same horizontal line, if possible.

(8) Authority or command lines should be heavier than rectangular outlines.

(9) Enter each rectangle at the center of the top line, and end it at the center of the bottom line or from the side of the rectangle. Command lines must not run through a rectangle.

(10) Place staff elements or personnel below the rectangle which represents the unit or person which they serve. They should be above line units, but staff elements do not intercept the command line to line units. If only one staff element exists, it is usually placed to the right of the rectangle, rather than below.

(11) Chart personnel staff directly from the box for which they perform staff duty.

(12) Arrange chart boxes to give a balanced appearance.

Having looked at some basic "rules" for making charts, it is natural to turn to more specific information about the development of such charts.

Organizational charts. Figure 3-1 illustrates a section chart in which all of the rules of chart construction were applied. Block 1 indicates the first level of authority above that of the section chief. Since this block is not an actual part of the section depicted, it is drawn slightly smaller than block 2. Block 2, the largest block, represents the person or section around which the whole chart is centered.

Blocks 3a, 3b, and 3c are on the next level of command below the key position. They are connected to the key position by solid dark lines. Why are these three blocks equal in size? They represent persons or sections equal in command. Blocks 4a and 4b are arranged horizontally, while the three 4c blocks are arranged vertically on the next lower level of command. These blocks are slightly smaller than those on the level above, and are often referred to as the workers' level.

Functional charts. The functional chart is a graphic presentation of the duties and functions of sections (or individuals) making up a unit. Normally, such charts are constructed along the same lines as organizational charts. The blocks in these charts contain unit positions and general outlines of the duties to be performed in those positions. Functional and organizational charts may be compressed into one, if local procedures allow.

The channel lines of a functional chart are similar to those for an organizational chart, but the blocks for a functional chart should be uniform. They must be large enough to contain the information desired, but only the primary functions should be listed. Include all applicable job titles, ranks, and grades. You may include names if you construct your chart so that the names can be readily changed.

Exercises (249):

1. State the position on an organizational chart which should be given the most prominent place.

2. State the comparative size of the rectangles around the block which identifies the main position.

3. State where staff elements should be placed on the organizational chart.

4. List the elements and relationships which a functional chart shows.

5. Name the specific items listed in the blocks of a functional chart.

6. State how a chart of an organization helps each individual within that organization.

7. List any errors contained in the organizational chart shown in figure 3-2.

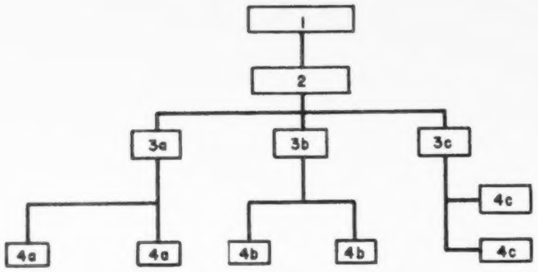


Figure 3-2. Organizational chart (objective 250, exercise 7).

250. List the functions and responsibilities of the Deputy Commander for Maintenance and state how the DCM covers such a large area of responsibilities.

Deputy Commander for Maintenance. The maintenance management concept depends upon centralized control of manpower and equipment. The Deputy Commander for Maintenance is the executive manager of the maintenance organization. This job is comparable to that of vice president of a large corporation. Through the use of staff agencies, the DCM controls, schedules, and monitors maintenance and inspection performed by all shops in the maintenance complex. The DCM programs facilities, equipment, manpower, and training requirements through study and analysis of the organization. The DCM must be highly qualified in leadership, management, and administration because the aircraft maintenance organization of one wing is larger and more complex than the operation of many commercial companies. The person who occupies the position of the DCM is usually the senior qualified maintenance officer in the organization. Many of the individuals occupying this position today in aircraft maintenance organizations are colonels. They have been in the Air Force long enough to be familiar with every aspect of the maintenance organization.

The DCM is responsible for assuring that instructions prescribed by all applicable maintenance data are followed, but will not look over your shoulder to insure that you are performing a certain task correctly. This responsibility will be met by a staff agency which has been given this responsibility. These agencies, 14 in all, are grouped under three staff functions (fig. 3-3): Management Support (no title in fig. 3-3), Quality Control, and Maintenance Control. We will discuss these in the following three objectives.

Exercises (250):

1. Name three areas in which the DCM should be highly qualified.

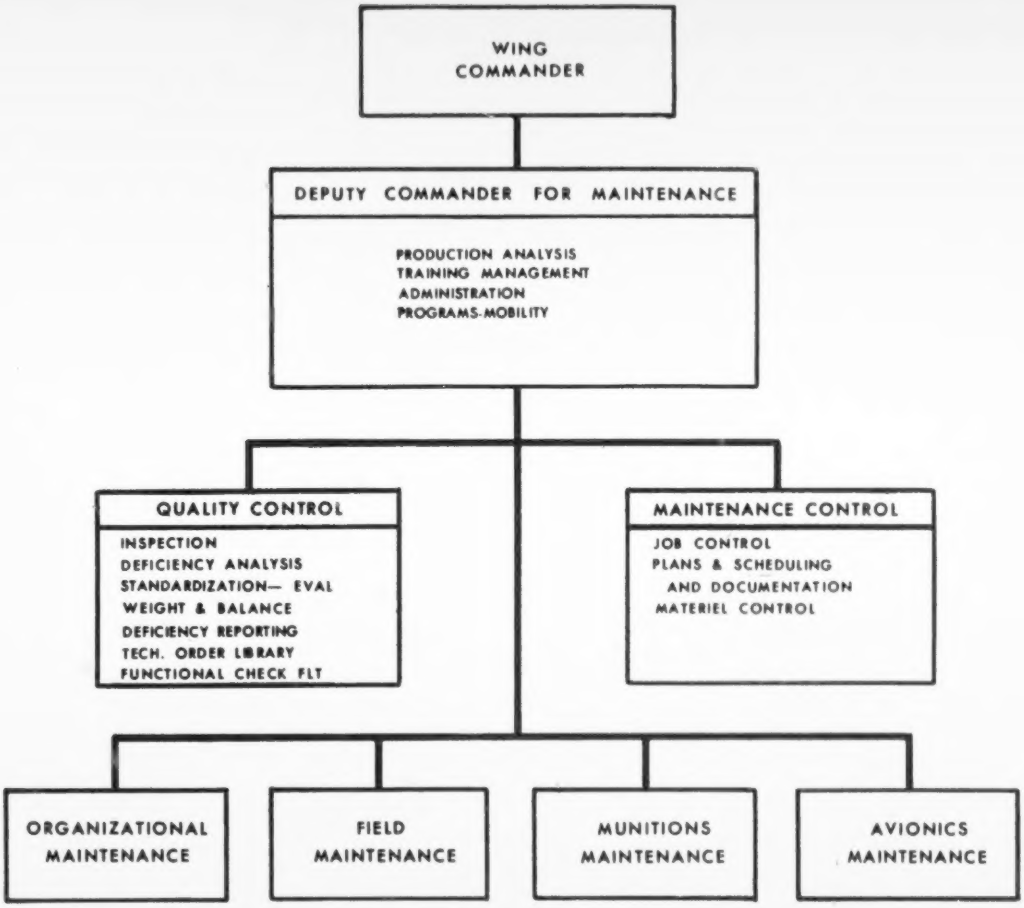

WING COMMANDER
DEPUTY COMMANDER FOR MAINTENANCE
PRODUCTION ANALYSIS
TRAINING MANAGEMENT
ADMINISTRATION
PROGRAMS-MOBILITY
QUALITY CONTROL
INSPECTION
DEFICIENCY ANALYSIS
STANDARDIZATION— EVAL
WEIGHT & BALANCE
DEFICIENCY REPORTING
TECH. ORDER LIBRARY
FUNCTIONAL CHECK FLT
MAINTENANCE CONTROL
JOB CONTROL
PLANS & SCHEDULING
AND DOCUMENTATION
MATERIEL CONTROL
ORGANIZATIONAL MAINTENANCE
FIELD MAINTENANCE
MUNITIONS MAINTENANCE
AVIONICS MAINTENANCE

Figure 3–3. Deputy Commander for Maintenance chart.

2. State the basic responsibility of the DCM.

3. State how the DCM covers such a large area of responsibilities.

4. List the three major functions that make up the DCM staff.

251. Identify basic responsibilities of the agencies that provide management support to the Deputy Commander for Maintenance, and define the term "management support."

Management Support. In figure 3-3, you will see the agencies that make up Management Support. Management Support is not an office or the title of an individual that can be placed in a position on the organizational chart. It is a term used to identify the staff agencies (management operations) that are not directly involved in maintenance production. They are grouped together under the DCM, and in the same block. This does not mean that they are in the chain of command between the maintenance squadrons and the Deputy Commander of Maintenance. It simply shows that they support the office of the DCM directly. The remaining agencies are grouped under the two staff functions of Quality Control and Maintenance Control. The management operations grouped under Management Support consist of production analysis, training management, administration, and programs and mobility.

Production analysis. Production analysis is the primary source of management information for the DCM. It serves as a data surveillance and statistical unit. The overall objective is to provide information which can be used to improve the maintenance operation. This is done by examining various maintenance data and reports.

Raw data can sometimes be misleading. By applying good analysis techniques, the production analyst can identify problem areas in the maintenance organization, as well as units which perform efficiently and represent a standard by which to judge others.

The more important functions of production analysis are listed below.

a. Collect and maintain data pertinent to the maintenance operation.

b. Review data for significant trends.

c. Isolate and identify areas which need further study.

d. Prepare studies and summaries as required by the DCM.

Training management. The basic responsibilities for training (within any maintenance organization) lies directly with the squadron commanders. However, the DCM is responsible for maintaining a balance of skills within the maintenance complex and insuring that maintenance personnel receive all necessary training. The Air Force has a continuous training program. Training management monitors and advises individual units on local training programs which develop skills on the job. They also help in planning training for skill progression. Training management acts as monitor and advisor. It does not exercise directive authority in the individual units.

Administration. The administration function is the administrative management center of the maintenance complex, and it is the focal point for all correspondence reporting. Administration maintains correspondence files, and it prepares and submits maintenance reports. Some of the duties of the administrative activity are listed below.

a. Establish and control a reporting and administration system for maintenance reports and correspondence.

b. Sort and group maintenance data forms before forwarding for keypunch.

c. Maintain correspondence and report files for the DCM.

d. Insure proper distribution of correspondence reports, standard publications, maintenance orders, and schedules.

e. Make timely pickup and delivery of maintenance forms and associated reports at maintenance activities and data automation.

Administration also supervises the keypunch activity when this function is assigned to the maintenance complex.

Programs and mobility. Programs and mobility provide the DCM with support in developing and maintaining currency of programs and plans. It also performs the functions of finance, manning, and facilities management for the DCM.

In today's Air Force, entire organizations must constantly be in a state of readiness for movement. Programs and mobility is responsible for developing internal procedures to insure that each maintenance activity is informed of mobility or contingency exercise requirements. In coordination with the unit mobility supervisor, programs and mobility will insure that maintenance activities accomplish the preparatory actions necessary to meet their mobility requirements. Programs and mobility reviews each mission plan, assures the DCM that the plan is sound, and assures that all contingencies are provided for.

Exercises (251):

1. 1. Place a letter from column B in each blank space next to column A to indicate which agency is responsible for that area.

Column A
Responsibilities

____ (1) Monitors local training programs.
____ (2) Controls reporting system for maintenance correspondence.
____ (3) Prepares studies for the DCM.
____ (4) Helps in planning OJT for skill progression.
____ (5) Collects and maintains maintenance data.
____ (6) Maintains correspondence files for the DCM.
____ (7) Distributes standard publications to maintenance activities.
____ (8) Reviews maintenance data for significant trends.
____ (9) Provides the DCM with financial data concerning the maintenance organization.
____ (10) Reviews and evaluates mission plans.

Column B
Agencies

a. Production Analysis.
b. Administration.
c. Training management.
d. Programs and mobility.

2. Define the term "Management Support."

252. Identify basic management responsibilities of the quality control sections of the Chief of Maintenance's staff.

Quality Control. High quality maintenance is the responsibility of all maintenance personnel. Quality control (QC), however, is particularly responsible for assuring that quality maintenance is performed throughout the maintenance organization. Personnel assigned to QC must be of the highest caliber. They must have the experience and background to inspect any maintenance and determine whether it is consistent with established standards. Refer to figure 3-3 as we discuss the responsibilities assigned to quality control.

Inspection. The inspection section determines the quality of maintenance by performing inspections on all maintenance activities and staff functions at least once a year. Further checks are made by performing spot and followup inspections.

Deficiency analysis. Deficiency analysis performs the technical investigation and troubleshooting phase of the problem analysis process. Deficiency analysis personnel must maintain a close working relationship with production analysis and with inspection. Some of the responsibilities of deficiency analysis are given below:

a. Develop and maintain job standards in coordination with other maintenance functions.

b. Recommend improvements to equipment utilization, procedures, work environment, and manpower utilization.

c. Analyze maintenance standardization evaluation reports, and man-hour consumption reports, and review inspection reports to determine trends and areas for further investigation.

Deficiency reporting. Deficiency reporting is closely related to deficiency analysis. Some of the duties of deficiency reporting are:

a. Process and control technical order improvement reports and deficiency reports.

b. Insure compliance with technical order procedures (on aircraft returning from depot or contract overhaul).

c. Maintain data required for materiel and publication deficiency studies.

d. Distribute corrective action information on deficiency reports, and inform the DCM of all unsatisfactory materiel reports submitted on assigned equipment.

Maintenance standardization evaluation program (MSEP). The objective of maintenance standardization is to improve maintenance quality and capability and the competence of mechanics and technicians. Through the use of MSEP, Quality Control encourages maintenance personnel to use standard maintenance practices and follow technical data procedures exactly. Periodically, highly qualified technicians evaluate maintenance personnel and equipment.

The MSEP is administered at unit level, permitting the DCM to focus attention on problems that need improvement. Point values and objective ratings are assigned to various areas. The MSEP gives the DCM an excellent tool for finding weak areas in the organization and the means to correct them. Here is an example: Personnel evaluations find unqualified personnel assigned to perform certain tasks. These people are singled out for further training, or other corrective measures are prescribed.

Weight and balance. The aircraft quality control supervisor serves as the unit weight and balance officer and is responsible for compliance with appropriate technical order procedures for weighing aircraft and for maintaining the required documents. Organizational maintenance or repair and reclamation personnel prepare, jack, and weigh the aircraft under the supervision of quality control weight and balance personnel. Quality Control personnel will verify scale readings and perform the computations.

Technical order library. Quality Control is responsible for maintaining an up-to-date technical order file. This includes inspection workcards, work unit code manuals, and checklists.

Modifications frequently require changes to technical orders. Each time compliance technical order lists the affected technical orders that must be changed as a result of the modification. Quality Control must insure that all replaced and changed pages are retained in the central file until the modification has been completed. Quality Control also inspects in-use technical orders during technical inspections to be sure that they are serviceable and up-to-date. When revisions are necessary for any of the in-use files throughout the maintenance complex, Quality Control advises all affected activities.

When technical orders have not been published for equipment assigned to the maintenance complex, Quality Control may establish a file of commercial publications relating to this equipment as authorized in AFR 8-2, *Air Force Technical Order (TO) System*, and TO 00-5-1.

Functional check flight. When certain types of maintenance have been performed on aircraft, it is a technical order requirement that the aircraft be given a functional check flight. Quality Control is assigned this responsibility. The various commanders must submit a written report to the functional check flight section of quality control, indicating the crews which are authorized to test assigned aircraft.

The functional check flight section has two important responsibilities. The most important is to assure that assigned aircraft are safe for flight. This is done through inspection and through functional testing of the aircraft in flight. The second responsibility is to accurately determine and report the quality of maintenance performed.

Exercises (252):

1. Name the staff agency under the DCM which is responsible for assuring quality maintenance in the maintenance complex.

2. Place a letter from column B next to each statement in column A to indicate which agency or program is responsible for that action.

Column A
Responsibility

____ (1) Inspect the instrument shop at least once a year.
____ (2) Assures that assigned aircraft are safe for flight.
____ (3) Maintains a file of commercial publications on equipment for which TOs have not been published.
____ (4) Evaluates performance to determine if it is in accordance with technical data.
____ (5) Develops and maintains job standards.
____ (6) Analyzes MSEP reports to determine trends and areas for further investigation.
____ (7) Processes and approves technical order improvement reports.

Column B
Agency or Program

a. Inspection.
b. Deficiency analysis.
c. Deficiency reporting.
d. Maintenance standardization and evaluation.
e. Weight and balance.
f. Technical order library.
g. Functional check flight.

Col A
Responsibility

____ (8) Informs the DCM of unsatisfactory materiel reports.
____ (9) Supervises weighing of aircraft.
____ (10) Performs annual followup inspections.
____ (11) Objective is to improve competence of mechanics and technicians.

253. Identify basic responsibilities of the management units that provide Maintenance Control for the Deputy Commander for Maintenance.

The management operations we will discuss next are grouped together under the staff function of Maintenance Control.

Maintenance Control. Maintenance Control and its subelements may be considered the nerve center of the maintenance organization. This activity controls the work within the maintenance complex, including the dispatch of specialists to the work areas. Separate areas of responsibility within Maintenance Control are: job control, plans and scheduling, documentation, and materiel control.

Job control. Personnel assigned to job control must be knowledgeable of the maintenance management system, and they must be qualified on at least one of the major weapon systems being maintained. Job controllers are in contact with all maintenance being performed. Each person assigned to job control must know the system being maintained, and must make decisions concerning specialist dispatch and maintenance scheduling on an hour-to-hour basis. No attempt will be made to list all of the duties of job control, but some of those duties are:

a. Maintain visual aids (status boards) showing the serial number, location, priority, status, fuel load, and configuration of each aerospace vehicle on station that is maintained by the maintenance complex.

b. Authorize and assign work priorities and start and completion times for unscheduled maintenance.

c. Control all maintenance on assigned aerospace vehicles and equipment.

d. Supervise and control the maintenance communications systems to provide an effective transmission of information on movement of materiel and maintenance personnel.

Plans and scheduling, and documentation. Many aircraft maintenance organizations have complex weapons and hundreds of maintenance personnel assigned. To attempt to manage such an organization without an efficient means of planning, scheduling, and documentation would be unthinkable. Maintenance planning and scheduling is mandatory to insure the effective use of maintenance resources. Long-range planning, such as for quarterly flying hour programs, quality control semiannual inspections, and training exercises, is needed to support future requirements. Plans and Scheduling forecasts and monitors long-range requirements through the use of monthly charts. These charts display requirements for at least the current month and the following two months.

Plans and Scheduling must compile and publish unit maintenance plans. They conduct daily maintenance planning meetings, confirming the daily portion of the weekly maintenance plan and the workload requirements.

The documentation activity maintains prescribed historical data. They are responsible for review, evaluation, and filing of information essential to planning and scheduling of maintenance actions. In addition to their other duties, documentation personnel review aircraft 781 series forms for accuracy and for validity of entries relating to other records.

Materiel control. The materiel control supervisor acts for the DCM to solve materiel problems. Materiel control has two basic functions: production control and maintenance supply liaison (MSL).

Maintenance supply liaison is primarily responsible for management of maintenance supply actions and for providing assistance to maintenance personnel in resolving supply problems. Some other duties of maintenance supply liaison are:

a. Operating tool cribs and establishing bench stock.

b. Recommending cannibalization, when necessary. (Cannibalization is the removing of a part from one inoperative piece of equipment to use in the repair of another inoperative piece of equipment, thus returning one of the two items to a serviceable condition.)

c. Participating in maintenance preinspection planning meetings.

Production control is responsible for two interrelated functions: shop scheduling and operating a reparable processing center. Some of the duties of production control are to:

a. Manage the reparable processing center (RPC) or reparable asset control center (RACC).

b. Control reparable assets within the maintenance complex.

c. Control shop work and assign in-shop priorities.

d. Process requests and manage local manufacture of approved items.

This concludes our discussion of the Deputy Commander for Maintenance staff functions. Although we have discussed each function separately, it is important to remember that all of these functions must coordinate closely as a management team in order to keep the maintenance organization operating efficiently.

Exercises (253):

1. Place a letter from column B next to each function in column A to indicate which agency is responsible for the function.

Column A
Responsibility

____ (1) Keeps up with the location and status of each aircraft on station that is maintained by the maintenance complex.

Column B
Agencies

a. Job control.
b. Plans and scheduling, and documentation.
c. Materiel control.

Col A
Responsibility

____ (2) Operates tool cribs.
____ (3) Processes a request for local manufacture of a requested item.
____ (4) Publishes the monthly maintenance plans.
____ (5) Assigns work priorities for unscheduled maintenance.
____ (6) Conducts the daily maintenance planning meeting.
____ (7) Supervises and controls the maintenance communication system.

254. Identify duties and responsibilities of the maintenance squadrons within the maintenance complex.

Maintenance Squadrons. Now let's take a look at the maintenance squadrons that do the actual maintenance. These squadrons are: Organizational Maintenance Squadron (OMS), Field Maintenance Squadron (FMS), Munitions Maintenance Squadron (MMS), and Avionics Maintenance Squadron (AMS). A knowledge of what each squadron is responsible for will give you a better idea of the overall function of the maintenance complex and help you to understand why some things must be done a certain way. As we discuss each squadron, refer to figure 3-3 to see how each fits into the maintenance structure. Notice that they are all on the same parallel functional line, below the Deputy Commander for Maintenance.

Organizational Maintenance Squadron. OMS has physical charge of the assigned aircraft. Each aircraft is assigned to an individual (usually called a crew chief), who is in charge of the aircraft, aircraft forms, and maintenance personnel assigned to work on the aircraft. We could say that the whole maintenance complex is organized to support the OMS. OMS may be further divided into the following branches:

- Alert Force.
- Base Flight and Transient.
- Flight Line.
- Inspection.
- Support Equipment.

Field Maintenance Squadron. FMS provides specialist assistance to the other maintenance squadrons. FMS is usually the largest squadron in the maintenance organization. It normally expends the most man-hours. The way personnel and equipment are used by FMS will greatly affect the wing maintenance capability. Ordinarily, the FMS is divided into the following branches:

- Fabrication.
- Propulsion.
- Aerospace Systems.
- Aerospace Ground Equipment.

Munitions Maintenance Squadron. MMS provides reliable and safe munitions for both conventional and nuclear weapons. This includes inspection and maintenance on weapons release systems. If guns are required on assigned aircraft, MMS will provide a gun services section to maintain and inspect gun system components. MMS may be divided into as many as seven branches, depending on the size of the organization. The maximum size unit would contain:

- Explosive Ordnance Disposal (EOD).
- Equipment Maintenance.
- Nontactical Instrumentation.
- Short Range Attack Missile (SRAM).
- Munitions Services.
- Munitions Maintenance and Storage.
- Preload.

Avionics Maintenance Squadron. AMS performs maintenance on avionics systems. Avionics systems include equipment such as communications and navigation radios, radar, electronic radar jamming devices, and other electronic systems. You are, or one day may be, assigned to this squadron; therefore, you should study figure 3-4 carefully. AMS may include any or all of the sections shown.

Exercises (254):

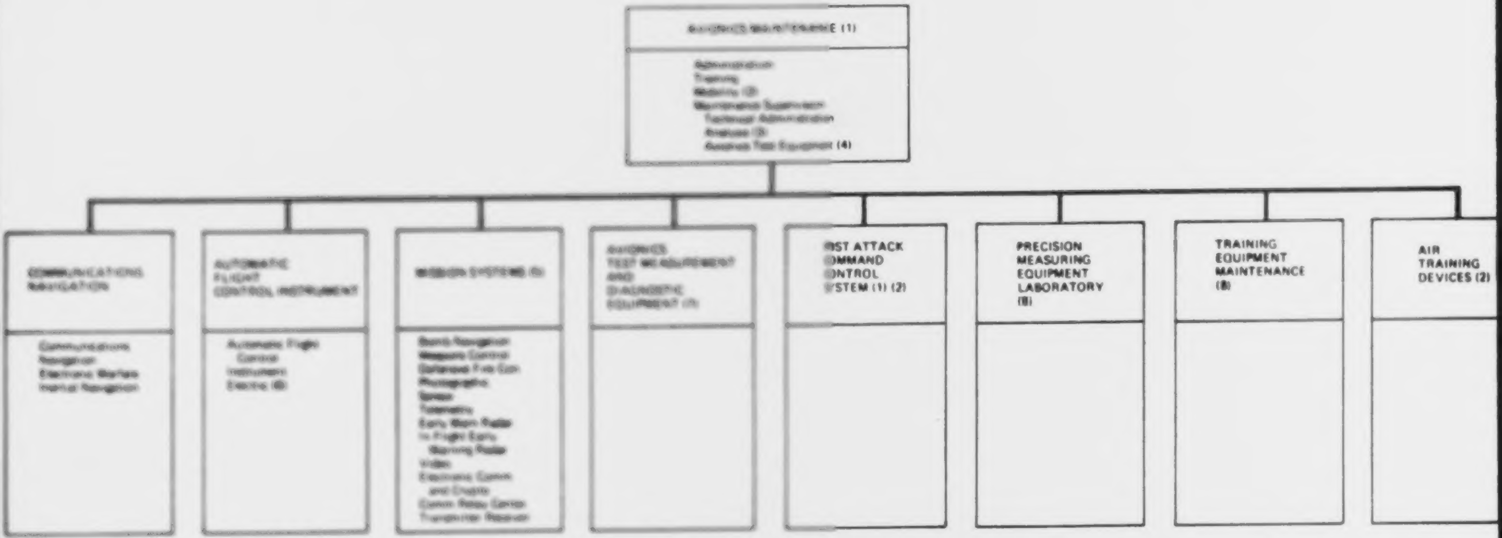
1. Place the initials of the squadron to which the function refers in front of each of the following:

_____ a. Maintains navigation equipment.
_____ b. Possesses assigned aircraft.
_____ c. Supplies specialists to perform an aircraft engine change.
_____ d. Maintains an explosive ordnance disposal facility.
_____ e. Operates a precision measurement equipment laboratory.
_____ f. Provides a gun service section if guns are required on assigned aircraft.
_____ g. Provides for base flight and transient maintenance.

2. Place the branch abbreviation in front of each shop to indicate which branch of the AMS it is a part of.

Branch Abbreviations
Comm/Nav—communications-navigation
AFCI—Automatic Flight Control-Instrument
Mission Systems—not abbreviated
PMEL—Precision Measuring Equipment Laboratory
ATD—Air Training Devices

____ a. Bombing Navigation (Bomb-Nav).
____ b. Electronic counter-measures (warfare) ECM.
____ c. Instrument.
____ d. Sensor.
____ e. Autopilot.
____ f. Pilot.


AVIONICS MAINTENANCE (1)
Administration
Training
Mobility (2)
Maintenance Supervision
Technical Administration
Analysis (3)
Avionics Test Equipment (4)
COMMUNICATIONS NAVIGATION
Communications
Navigation
Electronic Warfare
Inertial Navigation
AUTOMATIC FLIGHT CONTROL INSTRUMENT
Automatic Flight Control
Instrument
Electric (6)
MISSION SYSTEMS (5)
Bomb Navigation
Weapons Control
Defensive Fire Con
Photographic
Sensor
Telemetry
Early Warn Radar
In Flight Early Warning Radar
Video
Electronic Comm and Crypto
Comm Relay Center
Transmitter Receiver
AVIONICS TEST MEASUREMENT AND DIAGNOSTIC EQUIPMENT (7)
IST ATTACK
OMMAND
ONTROL
YSTEM (1) (2)
PRECISION MEASURING EQUIPMENT LABORATORY (8)
TRAINING EQUIPMENT MAINTENANCE (8)
AIR TRAINING DEVICES (2)

(1) Avionics maintenance will be organized as a squadron, division, branch, or section depending upon the size of the activity for aircraft equipped units.
(2) If authorized.
(3) Analysis authorized only for selected weapon systems based on complexity.
(4) An avionics test equipment function may be authorized to maintain, control, and issue common test equipment.
(5) Automatic flight control instrument branch or mission systems branch may be combined with the communication navigation branch when separate branch is not justified.

(6) Command option to align electrical systems under field maintenance.
(7) Authorized only for units having maintenance requirements for peculiar avionics TMDE and AGE.
(8) When authorized at technical training centers. This function can be divided into separate activities to align with the functional responsibilities at technical training centers. Training equipment assigned to avionics will be electronic oriented and may include missile equipment, communications-electronics training equipment, photographic equipment maintenance, and flight simulators.

Figure 3-4. Avionics maintenance organization chart.

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255. List the squadrons of a typical organization under the production oriented maintenance organization (POMD) concept, and state the functions of squadrons, shops, and specialists.

Production Oriented Maintenance Organization (POMO). This concept is primarily used by such major commands as TAC and ADC. Other commands are taking a close look at this concept to see if it can be adapted to fit their needs. POMO is not a new thing. In fact, it has been around for a long time. If you have ever gone TDY as a unit, you probably used this concept. You helped the crew chief take panels off, service, jack, and even tow the aircraft. You helped the other specialists (electricians, fuel, environmental) remove and install parts; and they, in turn, helped you. This was a temporary thing; as soon as you returned to your home station, you reverted back to the routine maintenance concepts. Under POMO, specialists are assigned to the aircraft squadrons permanently. These specialists, in addition to being current in their primary AFSC, will be qualified to perform general tasks such as towing, jacking, and washing the aircraft. Refer to figure 3-5 as we discuss a typical production oriented maintenance organization.

Under the production oriented maintenance organization concept, personnel are arranged into off- and on-aircraft production groups. You can see in figure 3-5 the staff functions under the Deputy Commander of Maintenance. The duties of the staff agencies under the DCM are slightly different under POMO; but for all practical purposes, they are basically the same as described previously. The squadrons which fall under the DCM are:

(1) Aircraft Generation Squadron (AGS).
(2) Component Repair Squadron (CRS).
(3) Equipment Maintenance Squadron (EMS).

Aircraft Generation Squadron (AGS). The Aircraft Generation Squadron is primarily concerned with on-equipment maintenance. The AGS will be organized into aircraft maintenance units (AMUs). The AMUs will then contain, in addition to the crew chiefs and crewmembers, specialists and weapons people necessary to perform the mission.

Component Repair Squadron (CRS). The Component Repair Squadron primarily repairs off-equipment aircraft and support equipment components. It will also assist in performing maintenance beyond the capability of the AGS and EMS. The squadron is functionally divided into three branches: (1) propulsion, (2) avionics, and (3) accessory maintenance.

Equipment Maintenance Squadron (EMS). The Equipment Maintenance Squadron is responsible for off-equipment maintenance of powered AGE (support equipment) and selected aircraft components such as drop tanks and munition storage. To find additional information concerning the production oriented maintenance organization concept, look at AFR 66–5.

Exercises (255):

1. List the three squadrons under POMO.

2. Name the squadron under POMO which is primarily used for on-equipment maintenance.

3. State what, besides the primary AFSC, a specialist has to know.

4. Name the squadron which the Aircraft Generation Squadron would normally call if assistance for maintenance was needed.

256. State the purpose of cross-utilization training and cite procedures concerning its use.

Cross-Utilization Training (CUT). The Air Force of today is greatly reduced in size. This means that we have to do the same jobs with far fewer people. To help resolve this problem, cross-utilization training was developed. It is defined as the training necessary to provide an individual with the ability to perform selected jobs in a cross-utilization AFS. Minimum training will be provided to the 2b proficiency level as shown in the cross-utilization specialty training standard (STS). The proficiency is not limited to the 2b level. Higher levels of proficiency are authorized and even encouraged. CUT will be made up of practical training and may include training conducted by the FTD. All individuals must be at the 5 skill level or higher in their primary AFSC to be trained for cross-utilization. Examples of cross-utilization are:

- Autopilot (325X0) to instruments (325X1) and instruments to autopilot.
- Communications (328X0) to navigation (328X1) and navigation to communications.

Cross-utilization training is documented on the cross-utilization specialty STS. This STS and the STS for your primary AFS are kept in AF Form 623, On-the-Job Training Record. You can see that being able to perform in more than one AFSC can greatly increase the mission capability without increasing the number of assigned personnel.

Exercises (256):

1. What is the purpose of CUT?

2. If your primary AFSC is 32551, can you be trained to the 3c proficiency level in AFSC 325X0? Give reasons for your answer.

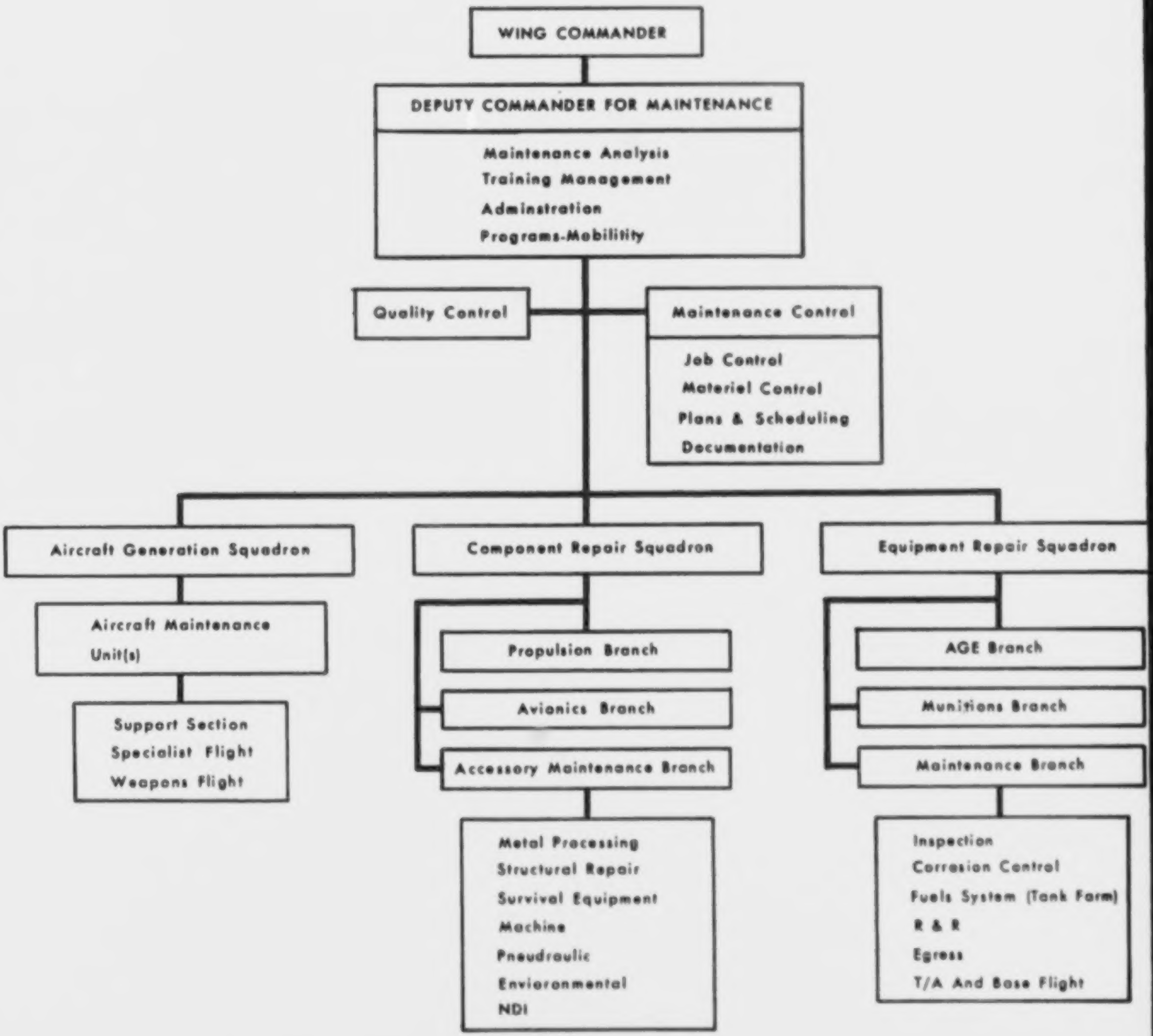
WING COMMANDER
DEPUTY COMMANDER FOR MAINTENANCE
Maintenance Analysis
Training Management
Administration
Programs-Mobilitity
Quality Control
Maintenance Control
Job Control
Materiel Control
Plans & Scheduling
Documentation
Aircraft Generation Squadron
Aircraft Maintenance Unit(s)
Support Section
Specialist Flight
Weapons Flight
Component Repair Squadron
Propulsion Branch
Avionics Branch
Accessory Maintenance Branch
Metal Processing
Structural Repair
Survival Equipment
Machine
Pneudraulic
Envioronmental
NDI
Equipment Repair Squadron
AGE Branch
Munitions Branch
Maintenance Branch
Inspection
Corrosion Control
Fuels System (Tank Farm)
R & R
Egress
T/A And Base Flight

Figure 3–5. Production oriented maintenance organizational chart.

3. As a 32531, which AFSC and to what level can you be given CUT? Why?

4. What document in AF Form 623 contains information on specific CUT tasks you are qualified to perform?

3-3. Maintenance and Inspection System

Most of us have had the unfortunate experience of having our car break down on the highway. Beyond the inconvenience of being stranded in the countryside short of our intended destination, we found that car troubles on the road are costly. Roadside mechanics have been said to have "cash register eyes." Costly repairs and inconvenience can generally be avoided by preventive maintenance of your car. If you take your car to a good garage for regular checkups, most breakdowns on the road can be avoided. But at least when an automobile quits, you can get out and walk.

When an aircraft breaks down in the air, it can be extremely hazardous for its occupants. Failures of aircraft equipment can be very costly, in both blood and dollars. Modern aircraft truly fly much like a brick when they have total engine failure in the air. Parachutes often save pilots and passengers, but not aircraft.

Why not prevent malfunctions before they happen? If certain parts are known to wear out after so much use, why not replace them at scheduled times before their probable failure? This, of course, is precisely what is done in the Air Force system of inspection and preventive maintenance. How well this system works depends directly upon how well you fulfill your duties. To become familiar with aircraft inspection methods, you will need to understand the objectives and breakdown of the maintenance and inspection system.

257. List the levels of the maintenance system; identify the AMS, AGS, EMS, or CRS level of maintenance; and match maintenance levels with maintenance actions.

The Three Levels of Maintenance. The three levels of maintenance from lowest to highest are organizational, intermediate, and depot. Maintenance and inspection policies are formulated by Air Force Logistics Command (AFLC). To support all Air Force organizations, AFLC has established air logistics centers that are charged with depot class maintenance.

Organizational Maintenance. Organizational maintenance is limited. It includes routine inspections, replacement of some components, minor structural repairs, and servicing with fuel, oil, etc. Organizational maintenance may also perform technical order modifications that can be performed with the facilities available at the organizational level.

Technicians at organizational level must discover indications of equipment failure soon enough to prevent major component failure. Failure to discover these indications results in an increase in the workload of other levels of maintenance, and may result in disruption of maintenance schedules. In-flight failure may result, with the possibility of loss of life and equipment.

Intermediate maintenance. Closely supporting the organizational level of maintenance is the intermediate level of maintenance. Personnel in the field maintenance activity, usually a Field Maintenance Squadron (FMS) or Avionics Maintenance Squadron (AMS), perform maintenance at the intermediate level. The AMS usually has the highest concentration of skilled specialists and costly equipment in the maintenance organization. The actual number will depend on the mission of the organization. If the Deputy Commander for Maintenance determines that there is a need for a function (shop), the organization will make a provision for it.

The support provided by this echelon (level of maintenance) consists primarily of furnishing specialist assistance to organizational line maintenance, performing bench checks of equipment, and maintenance repair that is beyond the capacity of the organizational unit. When the capabilities of the maintenance activities at the intermediate level are exceeded, the problem becomes a matter for depot level maintenance.

Depot maintenance. The highest level of maintenance requires extensive equipment to perform major repair and overhaul. The chief function of a depot is the performance of major maintenance on aircraft and all aircraft components. At depot overhaul, all systems are "inspected and repaired as necessary" (IRAN). Depot maintenance also supplies spare parts, aerospace ground equipment, and technical order compliance kits to organizational and field maintenance units.

Exercises (257):

1. Name the three levels of maintenance in the order of lowest level to highest level.

2. State the AMS level of maintenance.

3. Place a letter from column B next to each of the items in column A to indicate the level of maintenance.

Column A Maintenance Actions	*Column B* Levels of Maintenance
____ (1) Performs major overhaul of aircraft.	a. Organizational maintenance.
____ (2) Services aircraft with fuel and oil.	b. Intermediate maintenance.
____ (3) Performs maintenance for which the intermediate level does not have capabilities.	c. Depot maintenance.

Col A
Maintenance Actions

____ (4) Performs maintenance for which the organizational level does not have capabilities.
____ (5) Performs routine inspections of aircraft.

258. Name the three authorized scheduled inspection concepts, and specify how they are put to use.

Three authorized, scheduled inspection concepts are used by the Air Force: periodic (PE), phased (PH), and isochronal (ISO). We will discuss the basic inspections of each inspection concept.

Periodic Inspection Concept. We will discuss each of the five inspections used in the periodic concept, starting with the one performed most frequently.

Preflight. The preflight inspection, as the name implies, is basically a flight preparedness check. It is required before the first flight of the day. The preflight is a thorough visual inspection and an operational check of certain systems and components to assure that no defects exist that could cause accidents or mission aborts. Aircraft for alert status will have a complete preflight inspection before going on alert. After the alert period, another preflight will be performed before flight.

Throughflight. The throughflight inspection is applicable when an immediate turnaround or a continuation flight is scheduled. This inspection is made at intermediate stops. The aircraft is visually checked to see if there are any defects which could impair safety of flight.

Basic postflight. The basic postflight inspection is made after the last flight of the day, and only after the aircraft has been released to maintenance by operations. This inspection is to determine if the aircraft is suitable for another flight. A visual examination of certain systems and components is performed to assure that no defects exist which would be detrimental to further flight. The basic postflight inspection is a more thorough check than the preflight or throughflight inspections. Discrepancies found during the basic postflight can be repaired before the aircraft is scheduled to fly again.

Hourly postflight. The hourly postflight inspection is made after a specified number of flying hours have accumulated. It consists of checking certain components, areas, and systems of the aircraft. This inspection augments and is more detailed than the basic postflight, and may be accomplished at the same time as the basic postflight.

Periodic. The periodic inspection is a thorough inspection of the entire aircraft. It is more extensive than the basic or hourly postflight. In addition to the recurring inspection items, which are also required at the hourly postflight inspections, the periodic inspection includes certain components, areas, and systems of the aircraft that require less frequent inspection. The periodic inspection is due whenever a specified number of flying hours or a specified calendar period is expired. As in the case of the hourly postflight, the aircraft should not be scheduled for flight if the length of the mission will extend the flying hours between inspections by too great a margin.

Phased Inspection Concept. One bad feature of the periodic inspection concept is the long out-of-commission time required to accomplish the extensive periodic inspection. The phased inspection is actually a combination of the hourly postflight and the PE. Lumping these into one would make an inspection that requires an extremely long time to complete. Therefore, it is broken into small parts, or phases, having about the same work content.

Suppose, for example, that we have aircraft assigned with an hourly postflight required every 25 flying hours and a PE required every 200 flying hours. We could split the work accomplished on the PE into eight equal parts (200 ÷ 25 = 8) and do one part at each hourly postflight. We now have a phased inspection. Each phase will require more man-hours to complete than the hourly postflight, but no major inspection requiring a long out-of-commission time will ever be needed.

The main objective of the phased concept is to reduce the time an aircraft is out of commission for any given inspection. The phases are arranged in such a manner that each requires approximately the same number of man-hours. This arrangement permits all inspection requirements to be met while maintaining a short out-of-commission time for any one phase. The preflight, throughflight, and basic postflight inspections will normally be completed in the phased concept just as they would in the PE concept.

Isochronal Concept. "Isochronal" is a term meaning of equal term, or recurring at regular intervals. The isochronal concept is designed to translate flying-hour utilization rates into calendar periods, usually expressed in days. The inspection interval in days is based on the average flying hours for that period. Inspection is completed on the date due, regardless of the actual number of flying hours accrued. This helps eliminate the peaks and valleys associated with the periodic and phased concepts. Preflight and throughflight for the ISO remain the same as for the periodic and phased inspection concepts.

Home station check. The home station check consists of inspections when the aircraft returns from a long-range mission (possibly with several throughflight inspections at other bases), or upon expiration of a specified short-term calendar interval. These inspections cover items that would be included in the basic postflight and hourly postflight of other inspection systems.

Major inspection. The major inspection is a thorough and searching inspection of the entire aircraft. It is the most extensive inspection in the isochronal system, and is roughly equivalent to the periodic inspection.

Minor inspection. The minor inspection is designed to fill the gap between the home station check and the major inspection. It is more detailed than the home station check, and it inspects certain components, areas, or systems which require a more frequent check than is provided by the major inspection.

Exercises (258):

1. Name the three authorized, scheduled inspection concepts used by the Air Force.

2. When is a preflight inspection made?

3. State the purpose of the preflight inspection.

4. When is a throughflight inspection made?

5. Name the thorough and searching inspection of the complete aircraft for each inspection concept.

6. State the main objective of the phased inspection concept.

7. Name the two inspections which are used in all three inspection concepts.

8. State the concepts which the isochronal inspection is based on, and state the benefit derived from this concept.

259. Identify the factors to be considered before performing an inspection, match the four inspection phases with phase elements, and list basic equipment items.

Inspection Management. The procedures that follow provide a common approach to inspection management. Personnel, facilities, and equipment which support the inspection unit must be reviewed before the inspection, to insure that they are adequate to complete the programmed workload. These three components will be further explained to emphasize their importance.

Personnel. The skill and teamwork of inspection personnel determine the quality of the inspection. Inspection team integrity and stability insure proficiency on a particular type of aircraft. Initially, individuals should be trained to inspect a specific area. After they have developed proficiency in one area, they should be trained in another area. In this way, they become qualified in all areas of the aircraft. Personnel must be skilled in inspection procedures and techniques. On-the-job training of 3-level airmen provides a valuable means for upgrading inspection skills and techniques.

Facilities. The facilities available to the inspection unit depend on the location of the unit and the type of aircraft assigned. Facilities must have adequate heat, illumination, ventilation, and communications. The location should be accessible to supporting shops. The facility that provides the basis for greatest inspection efficiency should be used. Hangars or docks designated for scheduled inspections should be standardized.

Equipment. Inspections cannot be performed efficiently without the required tools and equipment. To minimize delays, each inspection section should have access to:

a. Applicable –6 inspection workcards, technical orders, and work unit code manuals.

b. Adequate hand and special tools.

c. Bench stock and petroleum products required for servicing.

d. A card bin for controlling inspection workcards and AFTO Forms 349.

Phases of the Inspection. An inspection should be carried on in accordance with a basic plan. Such a plan has been devised and is broken down into four phases. Most aircraft maintenance actions, and especially inspections, are performed in these four phases.

(1) Preinspection.
(2) Look.
(3) Fix.
(4) Postinspection.

Preinspection phase. The preinspection phase consists of a preinspection meeting, aircraft preparation, and inspection area preparation. The preinspection meeting is attended by plans and scheduling, documentation, supply liaison, and representatives from the organizational maintenance inspection branch. The discussions center around what can reasonably be accomplished within the time allotted. Requirements for performing maintenance relative to delayed discrepancies, TCTOs, time change items, and supply support are also discussed. The aircraft should be washed in preparation for inspection. The inspection area must be clean, and the necessary equipment and tools must be available.

Look phase. The look phase follows the preinspection phase. It consists of inspection of the aircraft in accordance with the applicable –6 inspection manual and workcards. Discrepancies are documented on AFTO Forms 349 and turned in to the supervisor or maintenance coordinator.

Fix phase. The fix phase may be started before the look phase is completed but should not interfere with the look phase. The fix phase consists of actions to correct discrepancies discovered during the look phase and to complete the preplanned maintenance which was determined during the preinspection phase. Discrepancy corrections are documented on AFTO Forms 349.

Postinspection phase. The postinspection phase begins when the fix phase is completed. It may be started earlier, however, if directed by maintenance control. This phase consists of:

a. Performing operational checks in accordance with the applicable –6 inspection workcards and technical orders.

b. Preparing the aircraft for functional check flight (FCF), when applicable.

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c. Correcting discrepancies discovered during post inspection operational checks and during and after the FCF.

Exercises (259):

1. State why the personnel requirement is so important to proper inspections.

2. List at least three basic requirements for adequate inspection facilities.

3. List the basic equipment which each inspection team should have in order to perform efficiently.

4. Match the phases of inspections in column B with the elements in column A.

Column A

____ (1) Washing.
____ (2) Equipment and tools available.
____ (3) Perform preplanned maintenance.
____ (4) Fulfill –6 workcard requirements.
____ (5) Preinspection meeting.
____ (6) Perform operational checks.
____ (7) Correct discrepancies.
____ (8) Clean inspection area.
____ (9) Document AFTO Form 349.
____ (10) Prepare aircraft for FCF when applicable.

Column B

a. Preinspection phase.
b. Look phase.
c. Fix phase.
d. Postinspection phase.

CHAPTER 4

Supervision

"Why should I study supervision? I'm not the boss."

You and all other people entering the Air Force are expected to progress in rank and responsibility. Each of you will be given opportunities to demonstrate and develop your supervisory and leadership abilities. Even in basic training and while in tech school, some of you were singled out as leaders. Now, your supervisors are looking closely at how well you get along with others, work with others, and accept responsibility.

When you complete your own OJT, you may be required to help train someone else. Even now, you may be trying to help your fellow trainees in things you understand but they don't. If you work with lower ranking airmen at all, you are supervising them to some degree by virtue of your rank. The odds are highly in favor of your being a supervisor at some time during your enlistment. Your first job as a supervisor may be training an airman just arriving from technical school, or you may be a shift supervisor.

The basic principle behind the Air Force promotion system is that each member must be able to lead as well as to follow.

4-1. Supervisors

What is a supervisor? A supervisor is an individual who directs the efforts of one person or several other people in getting a job done. A supervisor is a leader and a manager, the person who selects the individual, who lays out the details of the job, who makes sure necessary training is received, and who sees that equipment and materials are available to do the job. The quality of the supervision is measured not only by the degree of success but also by the manner in which the success was achieved and the willingness of the workers to perform for the supervisor.

260. Identify the traits of a leader by matching leadership traits to working situations.

Traits of a Leader. Very few of us are leaders in all situations. Actually, most of us spend more time being led than leading. To do a worthwhile job of supervision, you should acquire those traits that you most admire in leaders. We will start with the following list of good traits. It is by no means complete, and we expect you to add to it.

Initiative. Be able and willing to start new projects. Enjoy your work and project your enthusiasm to others.

Ability to make decisions. Make decisions based upon careful reasoning. Before making a decision, get the facts, weigh them, make your decision, back it up. Admit it when you don't know an answer but be sure to find the answer as soon as possible. Don't pretend to know the answer when you don't.

Interest in people. Have a sincere interest in people. Be able to listen sympathetically to their problems and make an effort to understand them. Then take whatever action is necessary.

Understanding. Realize that a person may not be at his or her best all the time. Trouble at home or outside worries can affect anyone's efficiency. Understand that your people are individuals and treat them as such.

Sincerity. Don't to be friendly and interested. Don't be a *hypocrite.* Make compliments only when you really mean them. Identify with your people; support them, even in their absence, provided they are in the right.

Pride in accomplishment. Have a sincere desire to see your people do good work. Don't be afraid that they will become as proficient as yourself. You should want your men to succeed and be proud when they do. Don't be afraid of your position, your subordinates, tough jobs, or honest mistakes. Give the impression that you are trying to work yourself out of your job and your people into it.

Patience and emotional control. Never assume that because a task is easy for you, it will also be easy for everyone else. Realize that the person to whom you must explain a task several times may later perform the job much better than the fast learner. Control your temper and think before you speak. A worker can hold a grudge a long time because of words you spoke too hastily. A worker with a grudge is not efficient. When necessary, give constructive criticism without losing your temper. When things go wrong on the job, appear calm and undisturbed; do not get frustrated. Straighten out problems with as little fuss as possible.

Fairness. Don't deal out favors to those who feed your ego. Establish fair production standards. When you evaluate a person, rate that person on actual performance (production and quality) rather than friendly overtures to you.

Personality. Personality is not what you have—it is what you do when you are with others. Success will come only when you have entirely forgotten yourself and, instead, are sensitive to others. Learn the art of forgetting yourself in a group. It isn't difficult; simply watch the other fellow and do what is appropriate. Think of each person as being a distinct individual whom you will try to understand and make a bit happier. Perhaps the best rule of action is the Golden Rule: "Do unto others as you would have them do unto you." Developing these traits in ourselves is essential. Equally important is understanding the basic needs of others.

Exercises (260):

1. The statement in column A may display more than one leadership trait. Enter the letter(s) of the appropriate trait(s) in the space provided in column A.

Column A

____ (1) Recognizes that the scheduling procedures being used tend to overwork some workers. The changes implemented correct the problem.

____ (2) Takes time to listen to the problem and suggestions that workers have, and takes necessary corrective actions.

____ (3) Compliments a worker for doing a good job and does not become frustrated when training a slow learner.

____ (4) Runs the shop with an even hand; does not play one worker off against another.

____ (5) Is easy to approach with a problem or suggestions and identifies with the workers.

Column B

a. Patience and emotional control.
b. Ability to make decisions.
c. Pride of accomplishment.
d. Interest in people.
e. Understanding.
f. Personality.
g. Initiative.
h. Sincerity.
i. Fairness.

4-2. Areas of supervisory concern

Here are three broad areas a supervisor must understand to be effective: *responsibilities, employee relations*, and *production*.

From your first day as a supervisor, you may be faced with many problems requiring immediate action. These problems can multiply at an alarming rate. Soon you may wish that you were back at the old job where life was fairly simple. A wrong decision, a careless remark, or a violation of a human relations principle may take months to straighten out. You may suddenly become aware that you are up against more than you expected. Supervision is not as easy as it looks!

A worker may be an expert technician but not necessarily a good supervisor. Sometimes a slow worker turns out to be a very good supervisor or administrator because he or she has learned the knack of getting work out of others and can get along well with people. Management is certainly much more than winning friends and influencing people, but the knack of getting others to work for you willingly is so important that a great deal of your time must be spent in promoting good "human relations." "Human relations" is the art of getting along with people. As a supervisor, you will be responsible for the output of others. You might not perform the actual production work yourself. Instead, you must be able to devise ways to get a good day's work out of those who work under you.

261. Given a series of job situations, state the basic human need each illustrates.

Basic Needs of People. The fact that a worker has reached a satisfactory production level doesn't mean that person is going to stay there without further attention. Many things cause people to "let down" in their performance. For apparently no reason, a worker changes overnight from a satisfactory, satisfied performer into an unhappy, low producer. One of the responsibilities of a supervisor is to determine the reasons. Then the supervisor can help the worker on the way back to high performance. This is a difficult job because there are no hard-and-fast rules that work for everyone. Workers aren't like machines. You can't push a button and make them do what you want of them. You can't just look at them to find out why they don't run right. Workers are people with ambitions that can be stirred, pride that can be hurt, nerves that can be shattered, and hopes that can be realized. This makes workers complex and difficult to understand, but you must understand them if you are to develop a satisfied, cooperative, and productive work force. To help you understand what makes people act as they do, you must know the basic needs of people. These basic needs are recognition, opportunity, security, and a feeling of belonging. Let's examine each of these.

Recognition. Every person has a basic need for recognition, and a personal way of expressing this need. Think about the following factors that make you feel you are being recognized: (1) receiving credit for what you do and praise for a job well done, (2) feeling that what you do is important and contributes to the success of your organization, (3) being allowed and encouraged to express your opinions in matters that affect you, (4) receiving adequate pay for your work, and (5) receiving the respect of your associates. Ask yourself, "Are these things important to me? Do I need to be satisfied and content in my job?" If you answer "Yes," and almost everybody does—then recognition is one of your basic needs. So when you are supervising people, do the following: tell them how they are doing; give them credit and a pat on the back; keep them informed; give them special assignments; and when the time is appropriate, consider and recommend promotions.

Opportunity. Opportunity is another basic need. The desire to improve our status is an important part of our job situation. Yet there are other types of opportunity that are also important to workers: the opportunity to do a good job, the opportunity for greater professional development on the job, and the opportunity to use one's abilities fully.

Security. This is another basic need that workers must have satisfied if they are to be content and adjusted to their jobs. This is not the security that is related to safeguarding military information. This security is feeling that the boss trusts you to do a good job without looking over your shoulder all the time. It is the feeling that you can keep your job as long as you do it well. In general, it is a sense of well-being and satisfaction about your job, your family, your associates, and your friends. As is true with the other basic needs, security doesn't mean the same thing to every person. Each of us has a somewhat different idea of security. To some, it is money in the bank; to others, it is a happy and secure home life; and to still others, it is a permanent job and firm future plans, like retirement. People's ideas of security change as they grow older. Although security doesn't mean the same to everyone, each individual strives for some kind of security.

Belonging. People are social by nature. The history of mankind is made up of stories about people banding together for a common cause. Driving into any average town proves this. On the way into town, you find signs announcing the meeting day and location of all sorts of civic and service clubs—Rotary, Kiwanis, Lions, and so on. None of these would exist if it weren't for people's desires to belong to groups and to wear pins to be identified with them. This desire to belong also exists among the people in offices and work shops. In addition to formal shop organizations, there are informal groups. Informal groups develop out of the common interests, likes, dislikes, and sentiments of people. People who enjoy the same sort of activities are drawn together because of the interest they share in those activities.

A supervisor must recognize that an informal organization exerts a very powerful influence over the productivity of the unit. Through the threat of losing status in the group, a worker can be influenced to adjust production either upward or downward. His or her attitude toward the boss can be affected—the worker doesn't dare to be friendly if the group he or she belongs to is hostile. Whatever conduct the group considers appropriate is the type of conduct you can expect from each member. The wise supervisor learns to recognize the leaders of the informal groups and to work through them. Even better, he or she is able to relate to the group and—through leadership abilities—become both the leader of the informal group and the leader in the shop (formal) organization. The supervisor must be alert to the forming of groups or cliques within the shop. A divided shop is like a "divided home." Even worse is the supervisor who falls into a clique and deals out special favors to it. The challenge to the supervisor is to find a way to influence the individuals who influence the other workers and not become their captive.

Exercises (261):

1. A worker who requests to be rotated from a job which he or she has mastered to a new job is trying to satisfy what basic human need?

2. A worker analyzes the procedures used in a job and develops a procedure that is better. By informing the supervisor of the finding, what basic need is the person trying to satisfy?

3. State the basic need that a worker has satisfied by quietly doing a task very well.

4. What basic need has been satisfied when an organization works as a team?

262. State how a supervisor can deal with individual differences and insure a smoothly operating shop.

Differences in Individuals. The basic needs we have just discussed are common to everyone, but they are not present to the same degree in each person. Some workers desire recognition above security; others want security more than anything else. For example, a young man just out of school may be more interested in an opportunity for advancement than in security. An older worker with several children and a mortgage on the house is probably more interested in security.

There are all sorts of differences in people: in attitudes, abilities, aptitudes, interests, experience, emotions, education, religion, age, knowledge, skill, physical strength, and many others. What do these differences mean to you? They should be very important to you. In particular, they have a bearing on assignments, they have a bearing on growth potential, and they have a bearing on the way the worker acts and reacts.

A person's feelings are more often conditioned by emotion than by fact and logic. A supervisor cannot easily change the emotional constitution of a worker; but, by studying the individual and the situation, he or she can learn how to help the worker adjust. Human needs seem to fall into four basic categories. Human differences also seem to fall into four different groupings: mental, emotional, physical, and social.

Individual differences affect the way you assign your work. If the work you want done requires heavy lifting, you need workers who are physically strong. If the work involves a lot of high pressure or mental strain, you need people who are emotionally stable. You wouldn't assign a new or inexperienced person to a troubleshooting project. You usually try to take advantage of a person's formal education and past experience when they relate to the type of work to be done. Here, again, we could go on and on, but these examples illustrate the importance of considering individual differences when assigning jobs to people. The supervisor, then, has to handle each individual differently if a good job atmosphere is to be established. Unfortunately, recognizing and satisfying each worker's basic needs are not simple tasks. Workers don't come to the supervisor and say "I want recognition," or "I want security," or "I want to be a part of the group." Rather, they reveal by their attitudes, emotions, and actions that these basic urges are motivating them. The indications are varied and sometimes even violent. When desires are thwarted, reactions result that should tell the supervisor that something is wrong.

The supervisor must know the workers and their individual desires well enough to help them get job satisfaction. This is the key to good human relations. To guide a worker's actions, a supervisor must know enough about the person to determine the approach to use to get positive reactions. Good human relations are based upon friendly contact and understanding. By an objective and orderly study of people, their desires, and their actions, you can develop a good technique for dealing with them.

Exercises (262):

1. State how a supervisor can deal with individual differences.

2. Why is it necessary for a supervisor to know the likes and dislikes of the workers?

263. Point out specific applications of the techniques of good human relations, and list the five techniques.

In the previous lesson we saw that all people have the same basic needs but that the degree of need the individual feels changes from time to time. Also the degree-of-need feelings vary among different people. Above all, the methods of satisfying the same needs are not identical. As a result, the alert supervisor remains flexible to developing techniques in deal with workers because each person responds best to a personalized technique which is appropriate for the problem, situation, or circumstances.

Techniques of Good Human Relations. When you become a supervisor, one of the first things you must learn is to "hang loose." Because a method of handling a problem worked one time does not mean that it will work every time or even once again. Every problem requires its very own solution. However, there are certain general techniques of good human relations that can be adapted to work with most people. They are used by successful supervisors. Let's examine several of them.

Let workers know where they stand. Workers need to know how they are getting along if they are to be happy and satisfied with their jobs. "Where they stand" includes whether they are doing a good job or not. How can you do this? You can take an interest in your workers and get to know each one personally. You can have periodic counseling sessions with each worker and see that each knows the job requirements. How often you counsel your workers and how close the personal relationship should be depends upon your individual work situation. There is a delicate balance between overfamiliarity and friendship. As a supervisor, you must walk the fine line of propriety or risk severe criticism. Criticism can be very damaging to the morale and productive output in your unit.

Give credit when due. This is another good technique to guide the supervisor in job relations. Experience has proved that this technique gets good results. It has been observed repeatedly that the supervisor who ignores it creates problems that cause lagging interest among the workers. But knowing the technique and knowing how to put it to use are two different things. Giving credit when due is a good idea, but how do you do it? There are many ways. Here are some of them: Give a worker a pat on the back and a little praise for a good job. Use letters of appreciation and commendation. Recommend outstanding performance ratings. Use the suggestion program that gives cash awards and other rewards for improvements developed by your people. Finally, do not overlook recommending personnel for promotion, upgrading, and better assignments.

Inform workers in advance and let them participate in planning. Supervisors can inform their workers of changes by personal contact with each individual, by written notices and bulletins, or by informal meetings and discussions. The latter is a good method, but calling workers together in a meeting does not automatically win their support and approval of changes. The supervisor still has the problem of getting workers's interest and participation. The idea that the change is needed must be sold and the workers made to want to take part in planning for it. The supervisor must encourage them to contribute their ideas and pitch in to meet the problems. It is the supervisor's attitude and conduct in general that makes workers willing to cooperate.

Gain the workers' confidence. Some ways to achieve this are to take a personal interest in each worker; to be friendly, helpful, and fair in your dealings; to encourage the workers to come to you with their problems; and to take action on the problem if at all possible.

We have discussed five ways of putting human relations techniques into practice. These are by no means all of the techniques that a supervisor can use. However, the five we discussed are of major importance and, when used properly, can be of great assistance to a supervisor.

Although techniques are useful in dealing with people, they will fail if they are not used properly. Supervisors may know theories of handling people, but when it comes to dealing with individuals, more specific knowledge is required. The supervisor must know the workers and their particular problems before attempting to apply techniques. He or she must study the individual worker, learn each one's personal interests, needs, and reactions. It is plain commonsense that satisfied workers perform better than unhappy workers. We repeat, your chances of having satisfied workers are greatly increased when you:

- Let each worker know where he or she stands.
- Give credit when due.
- Keep workers informed.
- Encourage workers' participation.
- Gain workers' confidence.

These five techniques are essential in good human relations. The supervisor who develops them will get better performance. A supervisor who recognizes these techniques and applies them with an understanding of the individual needs of the workers is described as a worker-centered supervisor—the kind of person who most often earns the title of "leader." The opposite of this is the "driver." The driver is concerned only with production and makes no effort to understand the workers. The big mistake this type of supervisor makes is the failure to recognize the importance of the individual in getting the work out. There is no doubt that the job gets done—but only to the accepted minimum.

Exercises (263):

1. Can every personnel problem be handled in the same way? Explain your answer.

2. If an experienced worker commits an error on a task which he or she normally does well, should the error be brought to the attention of the worker? Explain your answer.

3. State three ways a supervisor can give credit when it is due.

4. How can a supervisor get the attention of the workers to encourage them to participate in planning changes to the organizational structure of the shop?

5. List the five techniques of good human relations.

264. Differentiate between a supervisor who is a leader and one who is a driver and state the primary purpose of good supervision.

Motivation of People. Motivation can be both negative (fear) and positive (reward). The driver has a tendency to favor negative motivation. The leader favors positive motivation. Various studies show that positive techniques achieve desired results more often than negative techniques. This is not to say that a good supervisor is concerned only with making people happy. It is conceivable that a person who carried this to extremes would never get anything done. The worker-centered supervisor doesn't forget about the work to be done and isn't concerned only with keeping people happy. He or she relates the work to the individuals, thus winning their cooperation and support for the mission of the unit. A supervisor who builds good job relations can actually produce more than a supervisor who concentrates on production and drives the workers.

The mission comes first. Lest we give any false impressions in what we have said up to this point, we want to state in big, bold letters: THE MISSION COMES FIRST! Good human relations must never be distorted into unproductive practices. The purpose of an organization and of supervision is not merely to make happy workers. Its primary purpose is to accomplish the mission—in our case, top quality aircraft maintenance. What are the best techniques for accomplishing that mission? Practice good human relations as we have discussed them.

Exercises (264):

1. State how a supervisor who is a leader differs from one who is a driver.

2. State the primary purpose of good supervision.

4-3. Principles of Management

Most research by military and civilian managers and personnel specialists has proven that under certain conditions employees were loyal, cheerful, and productive. Under other conditions, they were uncooperative, beaten or resentful, and nonproductive. Analyzing the conditions and research produced theories which were tried and tested and eventually established as principles of management. Effectively organized and administered personnel management requires careful planning and clearly defined organization that is accurately directed, coordinated, and controlled.

265. Define planning, and list the four steps required in proper planning.

Planning. Prerequisites cannot be prescribed for the planning functions of management. Planning is essentially a technique for thinking through each job in advance, with the realization that no operation is too small to benefit from a planning technique. Planning is defined as foresight directed toward the manipulation of future developments so that they will serve the purpose of the organization.

A shop chief who has neither a general plan nor a plan for each day's work is shirking the job of supervision. The annals of wars, the histories of the rise and fall of big and little businesses, and even stories of a family picnic have proved that the planned activity is always the most successful. Learn how to plan and how to carry out the plan.

Planning requires the ability to visualize not only the end purpose or the finished job, but the whole procedure that will be involved in reaching that goal. A planner must have a background of related experience. Planning implies comparison of the projected undertaking with past jobs of similar nature.

Consciously considering all of the diversified activities involved, you must insure that these activities will be coordinated, and that they will work together toward the same purpose. Another essential undertaking is the inventory of material, equipment, and personnel. Finally, you must be able to check your plans in terms of their probable strength and weakness. You must appraise both positive and negative results.

Exercises (265):

1. Define planning.

2. List the four steps in proper planning.

266. List the steps in organizing and state considerations in making personnel assignments.

Organizing. When your plan has been formed, the function of organizing must be applied. There are three steps for the planner to follow: duty analysis, organizational chart, and assignments of personnel.

Duty analysis. The functional grouping principle must be used as a guide to divide the work into jobs which do not overlap. A person's duties should be clear-cut, specific, and similar.

Organizational chart. As you studied earlier, all supervisors should have personal organizational charts to use as constant reminders of where they fit, to whom they are responsible, and who is responsible to them.

Assignment of personnel. When assigning personnel to specific jobs or trying to understand why some one else was selected for a job, consider the following fundamentals of organization.

a. Unity of command. Each person should have only one boss. The authority to direct an individual must be limited to one person. You should know exactly to whom you report and from whom you receive directions. If the shop supervisor assigns an apprentice to work for you, then you become that person's boss. You should know it, and the apprentice should know it. The apprentice reports to you and is responsible to you. The shop supervisor still keeps control of the apprentice through you because you report to and are responsible to the shop chief. Even though there are other people over the shop chief, your job is to support your shop chief, just as he or she supports his or her supervisors.

b. Span of Control. One person can effectively supervise 3 to 7 workers. The most desirable number has been found to be 5. The number of people you can effectively supervise is your span of control. If the shop supervisor has three specialists and six apprentices in the shop, they can be divided into three groups with a specialist and two apprentices in each group. By directly supervising only the specialists, the supervisor concentrates his or her efforts in a reduced span of control; but by controlling the three specialists, the supervisor indirectly controls the six apprentices.

Distance, as well as numbers, limits the span of control. An instrument shop may have specialists working in the phase docks, on the flight line, and on the alert pad, all at the same time. This situation is handled by assigning a specialist in each group to supervise the group. Other factors which limit the span of control are the nature of the work and the skill of the worker. Simple tasks and skilled workers require less direct supervision; complicated jobs and unskilled personnel require more direct supervision.

c. Logical assignment. This is a functional grouping of the assortment of tasks in a worker's assignment. They should be related. The grouping of duties should make sense. If you assign a worker to repair complex machinery and to do typing, the assignment is illogical. The separate activities in the assignment should require generally similar skills at the same skill level.

d. Delegation of authority. When the responsibilities of a position or job are assigned to an individual, the necessary authority to accomplish the job must be delegated; however, the supervisor who is assigning responsibilities and delegating authority is still ultimately responsible. Authority may be delegated—responsibility cannot be. After a job has been passed down to the operational level, delegation must be limited. Coworkers, i.e., instrument 3 levels and 5 levels, must not be allowed to pass jobs to each other solely on the basis of rank.

Proper delegation of authority permits rapid decisionmaking. Every time a new echelon (or middleman) is added between the manger or supervisor and the worker, the flow of communication slows down and the risk of misinterpretation and misunderstanding increases. The lowest level decisions made within the framework of a clear understanding of objectives, functions, responsibilites, and authority are less costly because they do not clog communications channels, do not delay do productions, and provide training for you, our future managers, supervisors, and leaders.

Exercises (266):

1. List the steps in organizing.

2. Why should an organizational chart be developed from the duty analysis?

3. List the four fundamentals of organization.

4. If the shop to which you are assigned has 30 people, how does your shop chief reduce his or her span of control but still effectively control all 30 people.

5. State the violation involved in assigning three apprentices to a specialist for supervision but having them report to you.

6. State the violation involved when a position includes duties requiring unrelated skills at different skill levels.

7. You assigned Sgt Jones to train three apprentices, but required the training to be done your way. State the principle you violated.

267. Specify factors affecting the effective use of personnel and state how the use of personnel is monitored.

Effective Use of Personnel. Many factors should be considered in the decisionmaking processes of planning and organizing work assignments. Skill level and experience, job priority, and work distribution are important factors.

Skill level and experience. Knowing the skill level and experience of each worker will help you to assign work which will be a challenge. If the work is a challenge, it will keep the worker awake. If the job is a bore, workers tend to become careless and unhappy. This creates problems in morale and discipline. One way to prevent such problems is to rotate duty assignments. It is common practice for a person to pick out a job, learn it really well, and shy away from other jobs. It is a bad practice, and supervisors should try to rotate people so that everyone is checked out on such duties as in-shop repair, TO monitor, PMEL coordinator, shop dispatcher, and "paperwork shuffler."

Some supervisors assign an individual to assist in their paperwork duties (such as correcting maintenance documentation forms for correctness). These people are fulfilling some of the supervisory and management requirements for 5 and 7 skill level trainees. At the same time, these supervisors are training assistants who can free them from spending so much time in their offices and give them more opportunities to supervise the work being done outside of the shop.

An important advantage of duty rotation is that all jobs are covered when someone gets sick, takes leave, or is transferred. A good supervisor trains backup personnel for every position, including his or her own. Another advantage is that each worker has a broad knowledge of shop operation and is prepared for advancement.

Job priority. The priority of a job obviously affects your assignment of it. If completion of the job is very important to the mission, assign the best worker for its quick completion. For a lower priority job, you may be able to assign a less-experienced worker. This will broaden his or her experience and knowledge. Broadening a worker's experience benefits the worker, the Air Force, and the supervisor.

Work distribution. Work distribution is another important factor. The workload must be divided equally. You must not show favoritism by assigning the better or cleaner jobs to specific individuals. Distribute the jobs evenly among the specialists who have the same skill level. Failure to distribute work evenly and fairly causes hard feelings and unhappy workers.

Specialist Planning Chart. As a shop chief, shift supervisor, or interested member of the shop, you will want to monitor the progress of jobs in work, the number and status of jobs yet to be worked, and the location of dispatched personnel. The Specialist Planning Chart (fig. 4-1) or the Specialist Dispatch Control Log, AF Form 2430 (fig. 4-2), may be used for these purposes.

The Specialist Planning Chart should have a plastic overlay so that grease pencils may be used to make the entries. Each specialist dispatched should be indicated by a horizontal time line corresponding to the scheduled start and stop times. Brackets should be used at each end of the time line to highlight start and stop times. The job control number should be entered above the time line and the aircraft tail number, or the job location should be entered below the time line. Jobs that extend past their scheduled completion should be indicated by extending the time line in red. Shop work or absence from duty should also be entered on the chart. When scheduled action changes, entries on the planning chart should be changed, accordingly.

Assume that the Specialist Planning Chart in figure 4-1 is the current one for your shop. At 0745 you get a call from the branch requesting one worker for a detail between 0830 and 0930. You can look at the chart and tell that you will not have a worker available at this time. Miller and Peaters are working on aircraft 0922 until 0845. Francis and Jones will be on aircraft 5233 for the whole hour. Scrader is in the hospital. Most of this information can be found on individual work orders, but it's all graphically illustrated in one place for easy reference on the Specialist Planning Chart.

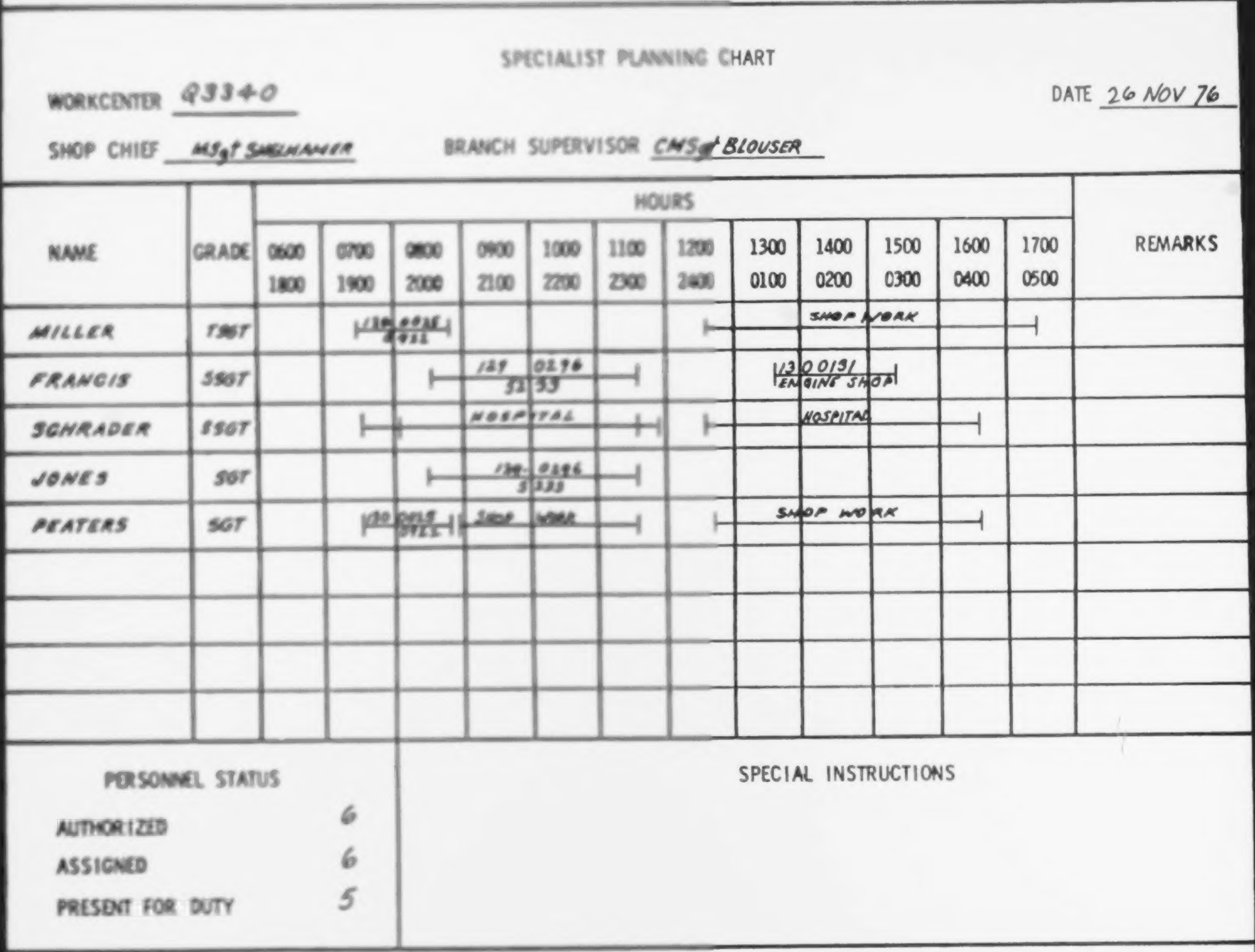
You may have noticed that there is no place on the AF Form 2430 to identify the using work center or shop supervisor. The reason for this is that the form is not kept after it has been used. It is supposed to be destroyed after its purpose has been served, either at the end of the shift or the end of the day. If the Specialist Planning Chart is used, the grease pencil entries are to be erased at the end of each shift.

Exercises (267):

1. Give three important considerations in deciding where to use personnel.

2. What type of work helps keep people's attention?

3. What does boredom on the job cause? What are the results?



SPECIALIST PLANNING CHART

WORKCENTER Q3340

DATE 26 NOV 76

SHOP CHIEF MSgt SHELHAMER

BRANCH SUPERVISOR CMSgt BLOUSER

NAME	GRADE	HOURS 0600 1800	0700 1900	0800 2000	0900 2100	1000 2200	1100 2300	1200 2400	1300 0100	1400 0200	1500 0300	1600 0400	1700 0500	REMARKS
MILLER	TSGT		130 0035 5011							SHOP WORK				
FRANCIS	SSGT				129 32	0296 53				130 0131 ENGINE SHOP				
SCHRADER	SSGT				HOSPITAL					HOSPITAL				
JONES	SGT				130	0296 3333								
PEATERS	SGT		130 0015 0911		SHOP	WORK				SHOP WORK				

PERSONNEL STATUS

AUTHORIZED 6
ASSIGNED 6
PRESENT FOR DUTY 5

SPECIAL INSTRUCTIONS

Figure 4-1. Specialist planning chart.

SPECIALIST DISPATCH CONTROL LOG	ASSIGNED	AVAILABLE	AVAILABLE FOR DISPATCH	AS OF
	6	5	4	0730 26 NOV 76

JOB CONTROL NUMBER	PRI	ACFT TRAINER EQUIP MDS	SERIAL NUMBER	LOCATION	JOB DURATION	TIME			SPECIALIST(S) DISPATCHED	DISCREPANCY & REMARKS
						REQUIRED	DISPATCHED	COMPLETED		
1300025	2	C130E	QA0922	101	2/1.0	0730	0730	0835	MILLER/PEATERS	#3 TACH FLUX REPLACED GENERATOR
1290296	3	C141A	QA5233	DK 2	2/3.0	0845	0830	1130	FRANCIS/JONES	C/W PHASE INSP COMPLETE
1300131	4	ENGINE	QE7688	ENGINE SHOP	1/2.0	1330	1330	1530	FRANCIS	JET CAL ENGINE C/W

AF FORM JUN 72 2430

Figure 4-2. Specialist dispatch control log.

4. State the advantages of rotating duty assignments. 5. You have two equally qualified workers, Ed and Pete. You receive a work request to complete a very complicated job, which has a low priority. Pete has experience at this type of job, but Ed hasn't. State to whom you should assign the job. Explain.

5. What two aids are authorized for use in monitoring work distribution, job assignment, job progress, and personnel locations?

6. State why brackets are used for the dispatch board.

7. State how jobs that extend past their completion time are annotated.

8. What is done with the Specialist Dispatch Control Log at the end of the day.

268. Define directing and state the factors which determine the type of directive to use.

Directing. Directing is often wrongly interpreted as just commanding or giving orders. It is true that commands or orders are used in directing; but remember, a command or order should not be given without planning, and it cannot be successful without organization, coordination, control, and knowing how to handle people.

Directing is the important activity between planning and organizing and actually doing. It consists of issuing instructions—guiding people in what to do, how to do it, and when to do it. The way the job is done depends upon a mutual understanding of the directions between the workers and the supervisor. Misunderstandings often arise because the directions mean one thing to the supervisor and another to the worker.

The framework for a large number of your directions is provided by such directives as regulations, manuals, technical orders, and operating instructions. Use these as guides when preparing instructions. However, there are situations that call for decisions and directions not covered by any directives you already have. In these cases you must issue your own directive. You should use your organizational objectives and good judgment as guides.

Of course, directions vary in different situations and with different workers. You sometimes must demand immediate no-nonsense action. In another situation, a mere suggestion of what should be done will be sufficient. If you are giving directions to a newly assigned person, you will probably use the request type of direction. Later you may decide to alter the type of direction you give that same person, according to his or her reaction. You may find that a command is necessary to motivate this particular person to action. On the other hand, a simple request may achieve the best performance.

With experienced workers, who have willing, cooperative attitudes, you will probably get the results you want with a suggestion or by asking for a volunteer. With experienced workers, the demand type of direction often causes worker resentment, tense relations, and dissatisfaction. With such people usually a suggestion will accomplish the desired results.

Exercises (268):

1. Define directing.

2. What factors determine the type of direction to use?

269. Compare oral and written directions.

Giving Oral and Written Directions. Worker reaction is determined to a great extent by the manner in which directions are given. Directions may be expressed orally or in writing, and each method has its advantagees. For example, it is foolish to give short, simple directions in writing and to give long, complicated directions orally. Sometimes an oral direction can supplement a written direction. This is useful when you wish to stimulate interest, explain why, or give an opportunity for questions. When you are issuing a new operating instruction, rule, or directive to your workers, it is sometimes wise to supplement these with an oral explanation. In this way, you can be sure that the new document is fully understood.

Complicated, detailed directions should be written. There are three reasons for this rule: (1) with written directions, nothing is overlooked, (2) written directions can be used as a check while the work is being done, and (3) written directions are a firm record of what was said.

When you are issuing directions, you can eliminate confusion by using the management tools of What? Why? When? Where? Who? How? If all of these questions are answered clearly in the directions you give, misunderstanding is reduced.

But sometimes, even when you have tried to answer all of these questions, your directions are still not effective. For example, your oral directions may not be understood because you assume that the worker has a full knowledge of the subject. You use words that are too technical, complex, unspecific, or long.

Likewise, a written direction can be misunderstood. For example, it may contain answers to the six questions and still be too lengthy or complicated. It may be arranged in an illogical sequence. It may make the work appear unduly difficult, or lack needed authority. You must be certain that you have included all of the needed information in your directions; but at the same time, you must make sure that it is clear.

Exercises (269):

1. When should oral directions be given?

2. Give three reasons for developing a written direction.

3. Why should oral directions sometimes be used to supplement written directions?

4. What important factors should you consider when writing directions?

270. State why a supervisor must have a positive attitude when directing workers.

Maintaining the proper attitude of a director. Consider the attitude of the director. Perhaps you have seen a supervisor give an order but suggest, by his/her attitude, that the order is unimportant. For example: "The chief wants us to count all those parts in the bench stock again. Take care of it as quickly as you can, will you, so that we can get at something worthwhile. Here's a copy of the count we made last week, if you want it!"

It isn't hard to predict the attitude of the workers assigned to this job. Their supervisor apparently thinks it's a waste of time. Therefore, the workers lose interest in the job and perform it carelessly. You must believe in the importance of the work you are doing if you are going to do it well and enjoy doing it. You must feel that the directions you give are important if you expect your workers to do their jobs well and enjoy doing them. Sometimes you must assume that the chief knows more than you do, perhaps even more than can be told to you.

Exercises (270):

1. Why must a supervisor have a positive attitude when directing workers?

172. Specify the management principle which permits small and large groups of people to work as a team.

Coordination. Proper planning, organizing, and directing will not guarantee successful supervision. The shop must work together and support the unit. The details of a plan, the organization of the shop and unit, and the directions must be related and coordinated. Coordination affects the total group effort more than any other single function. The efforts of the group must blend together as smoothly as the thousands of parts in an aircraft engine.

A supervisor, whether a trainer, a shift supervisor, a shop chief, or a higher level supervisor, must plan for coordination upward, to each side, and downward. All levels of management must work together. The plans of every supervisor must fit the objectives of the next higher supervisor and higher echelons of command. This is upward coordination. All supervisors on the same level, such as shift supervisors and shop chiefs, must also work together; this is coordination to each side. All supervisors must be sure that their supervisors at lower levels are informed of the objectives of the group and of the higher levels. This is downward coordination.

Coordination is not a job which is left to supervisors, job control, or production control. Every person is a coordinator. Each individual worker must work with others. Each helps coordinate the shop's activities by following instructions and doing each job well. Coordination demands communications; so, talk to your coworkers, your trainees, if any, and your supervisors. The more you talk to each other, the more you learn about each other, the closer you are to being a coordinated team.

Exercises (271):

1. What management principle affects the efforts of a group more than any other function?

2. Explain coordination to the side.

3. Your discussing a technical problem with the shop chief is an example of what type of coordination?

4. How can you help coordinate the activities of your shop?

272. State the uses of controlling.

Controlling. Each job, each task, each effort must be controlled. The control system must be in terms of standards of performance, and these standards must be used and enforced. Supervisors need these standards to evaluate the performance of subordinates, and those subordinates need them in order to know what is expected of them. Knowing what should be done, a worker is much more likely to do it.

Control directly affects all functions of management. The supervisor must know how well the shop is doing and if the workers are doing a good job. In other words, controlling is checking to see if the planning, organizing, directing, and coordinating is producing the desired results. There are many devices which may be used in controlling. They are valuable if properly used, but there is a danger of overuse. Many supervisors require unnecessary reports, charts, graphs, and other devices which do nothing but clutter up desks and files and hinder supervision.

Exercises (272):

1. What must supervisors use to control the quality of maintenance done by assigned specialist?

2. Which functions of management are affected by control?

3. How does your shop chief's method of control help you?

4-4. Evaluating Personnel

Evaluating is a three-step process: observing, assessing performance, and reporting. The basis of evaluating must be purposeful observation over a period of time. The time should be long enough to insure complete observation of performance. It should consist of direct observation of the individual's behavior, performance of duty, and quality of work.

The observed performance should be assessed in relation to each factor on the performance report. AFR 39-62, Volume 1, *Active Duty Noncommissioned Officer and Airman Performance Reports*, mentions the following criteria:

a. Inappropriate emphasis should not be given to isolated instances of poor or outstanding behavior.

b. Each NCO and airman must be judged in comparison only with other NCOs and airmen of the same grade and AFSC.

c. Evaluation should be based on observation made during the period of the report. If an incident occurred outside the reporting period, it may be included if it adds significant information that hasn't previously been reported.

The primary purpose of performance evaluation is to rate an airman's performance on a particular job against the duties or requirements of that job. Responsibility for evaluating the performance of personnel is both rewarding and awesome. It is rewarding because of the opportunity to award formal, individual recognition for good performance. It is awesome because of the significance the report will have upon careers. This responsibility is an inherent part of supervision, and it must not be taken lightly. Give careful consideration to all pertinent factors when you are preparing performance reports.

273. State guidelines to follow when you are establishing performance standards and state the value of such standards for the supervisor and for the worker.

Performance Requirements. Just as you feel that you have a right to know exactly what you supervisor expects from you, so do your workers have that right. You also believe that you should be told how your work will be judged. Those whom you supervise are no different. They want to know what their jobs are, and how you will go about judging their performance. A performance requirement (standard) describes what constitutes a job satisfactorily done. Included are factors such as quantity in a given time, quality, and manner of performance.

Determining performance requirements. Performance requirements should be realistic and practical. We frequently have difficulty in setting requirements because we overemphasize operating details of the job rather than the results we expect. Our objective is to require the results which the job must achieve in order to accomplish the mission. By setting the requirements at a reasonable level, we stimulate people to work. They are neither overworked nor underworked. We put within their reach, through a safe workload, the satisfaction of a job well done. You have probably seen what happens when workers are overworked. Some of these results are accidents, errors, fatigue, high turnover of personnel, resentment, and production slowdown. The situation is also bad when workers don't have enough to do. The results here are usually mischief (horseplay), excessive cost of operations, grievances, and absenteeism. Overload and underload are important in determining performance requirements.

Performance requirements must describe acceptable performance for each work operation. They should be set at a level which can be fairly expected of any qualified, competent worker who may be assigned to that job. Workers usually become frustrated and quit trying to reach a goal that is set too high. The requirement must be at a level attainable by average workers. Also, such a requirement leaves room for exceptional workers to perform above the requirement.

You can see the dangers of setting a requirement based only upon the level attained by the worker now assigned to the position. This assumes that the worker is meeting all the

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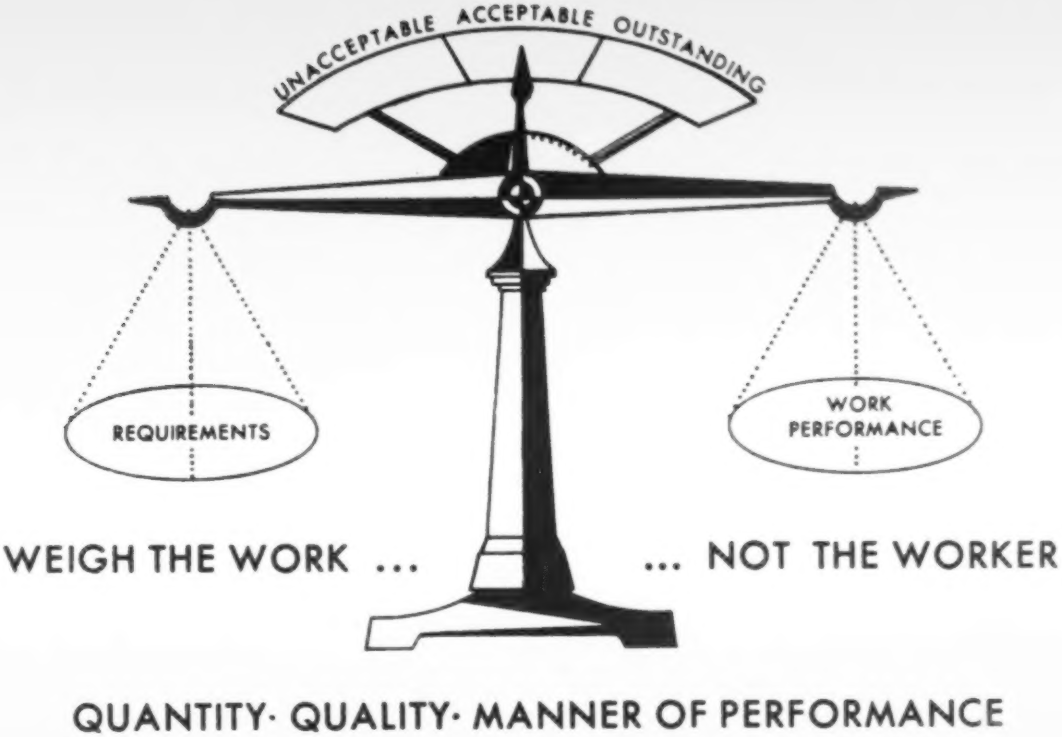

Figure 4-3. Scales (measuring work performance).

requirements of the position in exactly an acceptable manner. If the position is filled by a person of unusually high qualifications, it penalizes him or her by rating the outstanding performance as only satisfactory. The same situation would penalize future workers who were competent but not outstanding by rating their performance as unsatisfactory or unacceptable. If performance which is actually inadequate is used as the basis for writing performance requirements, the level of satisfactory performance will be too low.

Several steps or guidelines should be followed in establishing performance standards. The first step is to determine the task. The second is to analyze it for reasonable requirements (quality, quantity, time, and manner). The third step is to secure agreement from fellow supervisors, your workers, and your boss. Finally, set up the specific requirements.

Using performance requirements. Developing a set of performance requirements and placing them in a neat file is almost the same as doing nothing. They must be used if they are to be of any benefit. The supervisor must weigh the worker's performance continually and discuss it with him or her periodically. The scale pictured in figure 4-3 symbolically represents the idea behind measuring workers' performance against performance requirements. Notice that the work—not the worker—is compared with the requirement. The supervisor must (1) give recognition to workers who exceed requirements, (2) help workers who are below requirements (through training or by other appropriate means), and (3) motivate workers who are not doing acceptable work.

The supervisor gains from proper development and use of performance requirements. Minimum acceptable production goals for each worker aid production. Performance requirements create a sound basis for estimating future work capacity. They provide data for planning, organizing, and assigning work. They provide a basis for determining who needs additional training, and how much. Finally, they provide a sound basis for personnel actions and formal ratings. Another important supervisory function is the overall evaluation of personnel and the resulting personnel actions.

Exercises (273):

1. State the guidelines to follow when establishing performance standards.

2. State the value of performance standards to the supervisor.

3. State the value of performance requirements to a worker.

274. Identify the weaknesses of performance rating systems and characteristics which help eliminate those weaknesses.

Documenting and reporting performance. The performance of every individual in the Air Force is observed, evaluated, documented, and reported. This is done periodically on your performance, and you will eventually rate the performance of others. Every manager and supervisor must evaluate and rate the performance of his or her personnel.

The rater. Our real topic here is the performance reporting system, but no system can be covered adequately without discussing the reporting official or rater. This person is the key to the success or failure of any rating system.

Performance rating reflects one person's opinion of another person's performance. It is highly subjective and highly opinionated. The rater is human and is subject to human failings. You are not and will not be an exception. Your biases in at least five areas can affect the validity of a performance rating:

(1) You will like some people better than others.

(2) You will have pride in your unit.

(3) You will learn that it is easier to rate high than it is to rate low.

(4) You will remember unusual performance longer than you will remember typical performance.

(5) You will tend to apply a general impression, of one strong or weak quality, to entirely separate qualities.

Knowing these biasing tendencies, you must be as fair and accurate as possible, no matter how difficult this is. Whether you personally like the individual being rated really doesn't matter. If you give a worker a higher rating than deserved, you will endanger, if not destroy, the incentive of others who are really doing an outstanding job. If you give a higher rating than an airman deserves, you could cause the airman not to measure up to expectations when he or she goes to work for another supervisor. A drop in rating by the new supervisor could really hurt the promotion chances and career of the airman. If you underrate a worker who is obviously superior, the other airmen in your section will figure, "Why try harder? Look at the poor rating the best worker got."

Does all of this mean that ratings are worthless? Definitely not, even though ratings are indisputably subjective measurements. Return to our earlier statement that the rater is the key. What we have discussed only points out this "key" more dramatically. If the whole rating process depends on the rater, the rater must make a determined and sincere effort to recognize biases and make allowance for them. The rater must either possess or develop realistic standards, sound judgment, ability to communicate effectively, and a balanced personality.

Let's assume that you have conscientiously observed, and have carefully and fairly evaluated an airman's performance. You are ready to report the results on the rating form. This part of the process must also be done carefully. The space for "comments of the reporting official" will test your ability to communicate effectively with words. The completed report must accurately reflect all of the work you have done in the two previous steps. The finished product goes forward to serve as a factor in making many personnel decisions. Be sure that it represents a true and complete picture: who the airman is, what the job was, and how well it was performed.

Exercises (274):

1. State five factors which could bias the rating.

2. Name four basic characteristics which help a rater to eliminate bias.

3. List three distinct steps in the rating process.

275. Identify details in reporting the performance of airmen as outlined on reporting forms.

Specific Air Force forms are used in reporting the performance of Air Force personnel of different rank. We will discuss only the ones you need to know now.

Types of forms. Noncommissioned officer and airman performance ratings are recorded on one of the following:

- AF Form 909, Airman Performance Report.
- AF Form 910, TSgt, SSgt, and Sgt Performance Report.
- AF Form 911, CMSgt, SMSgt, and MSgt Performance Report.
- AF Form 77a, Supplemental sheet to the forms listed.

The determining factor for each form is based on the individual's grade at the closing date of the APR.

How performance reports are prepared. Performance reports are usually prepared in duplicate. Reproduction of these reports in whole or in part is prohibited except (1) for use in official personnel actions; (2) to complete personnel records when action fails to recover a missing copy; (3) upon written authority of the major command; and (4) as authorized by AFR 12-30, *Disclosure of Air Force Records to the Public*.

Information entered on performance reports must be typewritten or legibly printed with permanent reproducible ink. The rating boxes must be marked with an "X", whereas the column N/O (Not Observed) must be checked when there is insufficient knowledge. Neither corrections nor erasures are permitted on the front side of performance reports. Changes are permitted on the reverse side if the changes are initialed by the individual making the change. If a report contains excessive erasures or corrections, it should be redone. Reports may not contain classified information.

It is unlikely that you will be the reporting official for any of the top three grades for some time to come, so we will concentrate of AF Form 909. This form is used to evaluate airmen through the grade of senior airman.

Section I. This section identifies the person being rated, the period of the report, the reason for the report, and the AFSC in which work was performed. A performance report is required at least once a year or when there is a change in reporting official, whichever is sooner.

Section II, Duties. This section should identify the current duty, any additional duties, and all previous duties of the airman during the period of the report. It should accurately identify the specific duties of the individual.

Section III, Evaluation of Performance.

Item 1, Performance of duty. The airman should be rated on the quantity, quality, and timeliness of his or her work as described under the duties in Section II only. A zero (0) would be the lowest an airman could be rated, and a nine (9) would be the highest. N/O is used when the reporting official could not observe the performance of the airman and did not have enough information to make a valid report.

Item 2, Human relations. This area is used to tell how well the airman supports the equal opportunity program. It also includes the concern the airman shows for other people and the sensitivity shown toward the needs of others.

Item 3, Learning ability. How well and quickly does the airman understand instructions, principles, and concepts relating to the job? Can the person express his or her thoughts, ideas, and feelings accurately and easily so that others can understand? Can he or she teach others?

Item 4, Self-improvement efforts. How well has the airman progressed in OJT? Does the person strive for improved technical knowledge or a higher educational level which, in turn, will help on the job?

Item 5, Adaptability to military life. The customs and courtesies of military living are just as important as actual instrument systems maintenance. How well does the person accept the discipline and adapt and conform to the requirements of military living and duties other than shop duties?

Item 6, Bearing and behavior. The manner and degree to which the airman's bearing and behavior, both on and off duty, reflect upon the Air Force and other airmen should be considered here. Is the uniform worn properly? Is it neat and clean? Does the airman act immature or behave as an adult? Would you be proud or ashamed to say "This airman works for or with me?"

Section IV, Overall Evaluation. Here, the reporting official gets to express his or her opinion of how, overall, the airman compares to other airmen of the same rank doing the same type of job. Possible promotion and increased responsibility are essential considerations in this rating. If the airman is given another stripe, can he or she handle the added responsibility that goes with the stripe as well as or better than most other airmen? This is purely a subjective opinion based upon the evaluations made in Section III.

Section V, Rater's Comments. This section is used to substantiate the ratings in Section III. It should contain supporting facts, especially for exceptionally low or high ratings. The performance areas concerned with in this section are:

- Facts and specific achievements.
- Strengths (special things or characteristics deserving to be noticed).
- Recommended improvement areas (serious deficiencies, faults, bad habits, etc.).
- Educational and training accomplishments.
- Recommended assignments (specific).
- Other comments (include any comments not previously covered which add to the value of the report).

Performance reports are not the opinion of just one individual. Every report must be indorsed by the rater's supervisor and may even include higher ranking individuals. The airman being rated should not see the report until it becomes a matter of record unless it is a referral or bad report. Even then it is not to be used as a record of counseling because the individual should have been counselled several times before a referral report was submitted.

Although airmen should not see their performance reports before they become official records, each individual should have a good idea of how he or she is going to be rated, even before the APR is written. If isn't too difficult to figure out if you are doing a good job, what your deficiencies are, and the areas in which you need to improve.

Once the APR becomes part of your records, you may read it to see exactly how you were rated. If you haven't done so, you are encouraged to go to CBPO and read the official report on your performance. Your doing so should make it easier for you to rate someone else fairly.

Preparing letters of evaluation. There are instances when the reporting official (for AF Form 909, 910, 911) does not have the opportunity to observe a subordinate's performance and personal qualities. The reporting official may request a letter of evaluation from some person in the ratee's unit. This designated person should be familiar with the duty performance of the ratee. The letter of evaluation should include as much pertinent information as is available. It is prepared on AF Form 77a with the contents organized in the format suggested for Section V of AF Form 909. The letter of evaluation can be used by the reporting official to aid in preparing the AF Form 909, or it can be attached to the report.

Exercises (275):

1. On which AF Form will a 3 level's performance normally be rated?

2. What factor determines which form a person's performance is rated on?

3. State when an APR is required.

4. What type of information should be entered in Section II of AF Form 909?

5. You will be given a rating between zero (0) and nine (9) in each of what seven areas?

6. Possible advancement is a necessary consideration in which rating?

7. The person who rates your performance will probably write some justification for your ratings in what areas?

8. When can you see exactly how your performance was rated by reading the actual report?

9. If you were TDY for 60 days of the reporting period, how could your reporting official rate your performance during the time you were away?

4-5. Problem Solving

Every day supervisors encounter new problems. If all of us solved problems in exactly the same way, we would have to have the same thought processes. Of course, we do not think alike, but all of those who are able to find proper solutions quickly and easily have something in common. They follow a fairly well-established pattern of thought and action.

276. Name the steps in problem solving.

There is no trick or magic formula for solving problems, but those who are most successful at it follow an orderly, organized process, as follows:

- Define the problem.
- Establish objectives.
- Gather facts.
- Weigh and decide.
- Take action.
- Evaluate action.

Define the Problem. This is the first step in problem solving. When trouble arises, you say that you have a problem, but you are likely to find that it is difficult to put into words. Yet if you cannot state the situation clearly, it is hard to know exactly what you want to do about it. Defining your problem clearly leads you to the next step, setting your objectives. For example, a supervisor is faced with what seems to be a problem of absenteeism. However, further study of the situation reveals that the real problem is transportation, housing, sickness, accident, or even squadron duty. A high percentage of poor work can surface from a problem of forced machine speeds, poor material, lack of training, or a number of less obvious reasons.

Establish Objectives. To determine objectives, you need to know the whole story. You can do this only by securing as much information as possible in the time available. It is poor management to risk a decision without sufficient facts. Granted, there are times when a decision must be made on the spur of the moment because of the nature of the situation. But even then, every possible attempt should be made to get all the information possible before making the decision. Remember, your objectives establish the purpose of your further study.

Gather Facts. There are a number of sources from which you can obtain information—records, rules, regulations, and technical orders. Workers who are concerned with the problem may very well be better informed about it than the supervisor. It may be as important to get their opinions and feelings as it is to get the facts. Supervisors can gain information by listening to workers talk about the situation, by keeping their eyes open and observing what is happening, by reviewing records and policies, by asking questions, and, if practicable, by delegating the gathering of facts to an assistant.

One question that may seem puzzling is this, "How can you tell when you have all the significant information or at least enough to help solve the problem?" Perhaps the best guidance in answer to this question is that, as you consider the facts, they begin to fit together to form a pattern. If the picture they form has missing pieces, some facts must be missing. Maybe a second, closer look will uncover them. On the other hand, if they add up to the answer, you need look no further. However, if you have some important facts left over that do not seem to fit in, maybe your diagnosis is wrong. Before you discard any facts, really think about them. Sometimes important solutions, even new discoveries, are made by a person who can find a relationship between facts that others have passed over as unimportant.

Weigh and Decide. What we have been saying is that after you get the information, you have to fit the facts together and consider their bearing on each other. You can help clarify their relationship to each other by asking yourself such questions as: What caused this to happen? Who was responsible there? Did this happen before or after that? Soon the facts will fit together like a jigsaw puzzle to form a clear picture. As you think about the problem and analyze the facts, possible solutions will occur to you. List every reasonable solution for careful review later. As you do this, you will want to consider the effects of each proposed solution on individuals, groups, production, etc.

This process enables you to select the best action to take. Other considerations with a bearing on the action to take are time, manpower, money, equipment, supplies, and other resources.

Take Action. Up to this point, we have discussed ways to make a sound decision; but we cannot leave it here. All the effort and time spent in arriving at this decision is wasted if favorable action does not result. A supervisor who delays or fails to take decisive action is avoiding his or her responsibility. When you are taking final action on a problem, consider these questions: Should I handle this myself? Do I need help in handling it? When and where should final action be taken?

Evaluate Action. The best laid plans and the most carefully made decisions sometimes do not work out exactly as intended. Many times you cannot get all the pertinent facts in the time available. It may be that some of the facts on which you based your judgment are false or misleading. It is essential that you check on how your solution is working out. Obviously, it is better to find out for yourself that it is not working and to make the correction yourself than to wait for your boss to find out. You should be the first to know it, acknowledge it, and correct it.

Exercises (276):

1. What is the first step in solving a problem? Why is this step important?

2. After a problem has been identified, why should objectives be established?

3. List several sources of information about a problem.

4. State why the facts must be weighed and analyzed before a decision is made to take specific action to correct the problem.

5. What is the last step in problem solving? Why is this step important?

277. State how procedures for resolving the personal problems of a worker are used, and point out the difference between a worker with problems and a problem worker.

Resolving Personal Problems. There are workers with problems, and there are problem workers. Good supervisors are able to distinguish between the two. This ability is a fundamental requirement for effective supervision. Entirely different approaches are necessary to correct the two situations.

Workers with problems. Workers with problems may need assistance from the supervisor or from some other qualified person. It is too bad that people are unable to keep their problems from affecting their work, but few can. Therefore, the more of their problems that you help resolve, the less these problems will affect their work. Worker's problems normally do not follow a particular pattern. Each one must receive special attention.

Problem workers. The problem worker belongs to an entirely different category than the worker with a problem. This individual fails to respond to efforts to help. He or she does not want help, but wants to cause trouble. Through his or her actions, or lack of action, this person disrupts others who are trying to do a good job. In such a situation, corrective measures must be taken. A regulating system has been set up to assist in handling severe cases.

It is obvious that a good supervisor should deal firmly with problem workers. At the same time, if the problems are to be solved, action should be directed at causes rather than at people. Whenever you must deal with severe problems involving people, always ask yourself, "Am I trying to fix the mistake or fix the blame?"

You have to realize that some people will cause trouble no matter how conscientiously you apply the techniques of good human relations. But this doesn't mean that these techniques aren't worthwhile. Remember, their proper application will reduce the frequency and type of difficulties you encounter.

There may be problems you cannot solve without the help of your supervisor. There may be others you cannot solve without the help of some staff agency, such as the personnel office. You can solve problems within the scope of your authority without outside help, but those beyond your authority must be referred, through formal channels, to higher authority for action. By far the best procedure is to handle dissatisfactions before they get into formal channels. Try to stop trouble in its early stages before it gets out of hand.

Discussing problems. Since a worker's problems are also the supervisor's problems, how can you handle them? You can use the systematic problem- solving techniques. If a worker shows signs of being in trouble, talk to him or her to find out what is wrong. Be sure to gather whatever information is available before the talk. Talk in a private place. Be a good listener. Base the discussion on facts, and follow up.

It is easy to see why these factors are important. Since the purpose of talking is to get the worker's story, the reason for letting the individual do most of the talking is obvious.

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When you hear the facts, it may help for you to restate the problem just to be sure you understand the situation. Define the problem with the individual. This is often an effective way to help a person clarify the situation in his or her own mind. You can also ask for clarification on some points that may cause the person to reevaluate the problem. The process of restating the problem sometimes suggest a solution. By listening, the supervisor has gathered valuable facts, and may have put the complaining worker in a better frame of mind.

The nature of the complaint will suggest whether it must be investigated further, whether you can handle it yourself, or whether it must be referred to someone else. You will find that many of the dissatisfactions of your workers are relatively small problems with easy solutions. But even little problems can grow into big problems if they are mishandled or ignored. A dissatisfied or disgruntled worker finds fault with many things and can stir up trouble among other workers.

This points out the necessity of trying to stop trouble in its early stages. Sometimes this is difficult to do unless you are alert and have studied the individual differences among your people. Maintain a good relationship with each worker to be sure that they aren't afraid to discuss their problems with you. If a supervisor has earned respect and confidence, people will come to him or her with their problems. This is a true test of the confidence that your workers place in you. In many cases a worker who has trouble off the job either consciously or unconsciously transfers these troubles to the job. If the supervisor's first indication of the difficulty is when the worker begins to be a problem, it is apparent that the supervisor has not gained the worker's confidence.

Exercises (277):

1. How does a worker with a problem differ from a problem worker?
2. When you are attempting to solve a worker's personal problem, where should your action be directed?
3. Will the techniques of good human relations always solve or prevent personal problems? Why?
4. How does listening to a worker's problem help the supervisor?
5. State why it is essential for the supervisor to gain the confidence of the workers.

278. Identify the actions which can be taken to correct substandard personnel performance.

Correcting Substandard Performance. As we stated earlier, when a unit begins to fall below standards, a program should be set up to correct the problem quickly. The same is true in personnel standards. If a supervisor observes sloppy workmanship, poor grooming, or missed appointments or training sessions, action should be taken. As a supervisor, you must apply corrective action to fit the situation.

Correcting substandard personnel must be done quickly but fairly. We can begin with a simple counseling session to inform the airman of what is expected at all times. This may be all the action required. In some cases, we may have to use several of these counseling sessions before standards are met.

For personnel who cannot be corrected by counseling sessions, we may initiate the next step. We could discuss the situation and facts with the commander. The commander may now apply greater pressure on the individual in the form of reprimands. There are two types of reprimands that can be used. The first is the verbal reprimand. This is much like the counseling at section level. Normally, the individual begins to understand that continued substandard performance may bring even more severe consequences. The second type of reprimand is a written reprimand. This is entered into the individual's records and will reduce the probability of promotion. The commander has a few more avenues open. The Article 15 can be used as squadron level punishment. Under the Article 15, the commander can reduce the individual in rank, fine the individual, or both. In severe cases, the commander may elect to refer the case for court-martial. This may even lead to a recommendation for discharge under conditions of AFM 39–12, *Separation for Unsuitability, Misconduct; Resignation or Request for Discharge for the Good of the Service; and Procedures for Rehabilitation Program*. This report, of course, is rarely used, but such actions have occurred.

Exercises (278):

1. What action can the supervisor take to correct substandard performance by an individual?
2. What should the supervisor point out to the individual during counseling?
3. What action can be used if counseling has little or no effect?

4. List corrective actions which the squadron commander may take at squadron level.

5. What punishment is used as a last resort for substandard performance?

279. State why the size of instrument shops vary and why it is necessary to justify requests for more people.

When you are put in a supervisory position, your primary concerns will probably be the size of the workload and the people and equipment assigned. Your primary objective will be production. The mission of your unit determines the number and skill level of the people authorized in your shop.

Justifying Personnel. The Air Force publishes manpower standards. Personnel requirements are based on the type and number of aircraft assigned and on the number of hours these aircraft fly.

Assume that the shop has a big backlog of work orders. You must find out if the recent flow of work has been abnormal. The amount of work flowing into a shop will vary from week to week. Perhaps it will level off in a few days. Do not conclude immediately that the number of people authorized is inadequate. Perhaps the number of people assigned is correct but their skill levels are below those authorized. The manning document may authorize one technician, three specialists, and two apprentices for your shop, while one technician, one specialist, and four apprentices are assigned. You may have enough people, but they may not have the skills authorized for the shop.

Unauthorized skill levels do not justify additional personnel; but if this is the problem, the solution is either to request two more specialists or to train at least two of the apprentices to qualify as specialists. If a work order backlog persists, or if you must continually work overtime to keep the backlog down, you manning authorization may not be realistic. If you decide that you need more personnel, evidence to justify the increase must be supplied with the manning request. Programs and Mobility will initiate correspondence for the Deputy Commander of Maintenance, effecting the necessary actions with manpower or personnel agencies to adjust future maintenance manning positions. They will work closely with production supervisors (you, in this case), management engineering teams, and the production analysis activity to support the manpower change request. This type of justification is necessary to insure that a shop does not become overpopulated for the amount of work it is normally assigned. Overpopulating a shop in relation to its workload is a waste of Air Force dollars. This is bad management.

All justifications, whether for personnel or equipment, must be centered around the shop mission. If you cannot show the need to your mission, you have no need for personnel or equipment.

Exercises (279):

1. State why it is necessary to justify requests for additional personnel.

2. State the primary factor in the justification of personnel.

3. Name two Deputy Commander of Maintenance staff agencies which you will probably work with when you are justifying additional personnel.

280. Point out specific uses for maintenance and inspection reports.

Maintenance and Inspection Reports. Maintenance and inspection reports are very important in the life of a supervisor. The daily and monthly maintenance reports tell where workers are being employed for most of their time. These reports are prepared from information supplied on maintenance forms. Besides the maintenance reports you have on file, the squadron analysis section keeps a complete record of each writeup received from the aircraft crewmembers and ground crews. This information is also supplied by maintenance forms.

The job description for the 7 level in your career field states that technicians are called on to solve very difficult tasks. Since they are widely experienced, they do not rush out to the aircraft without first checking the background information on the aircraft. A technician checks the aircraft history file at the analysis section to pinpoint a possible cause before going to the aircraft. This procedure is often overlooked by less experienced workers. It is always good practice to check or have your workers check the aircraft's past history.

They will find it on AFTO Form 95, *Significant Historical Data*. This historical record is kept at the analysis section. The facts are compiled from the maintenance information furnished by both the flight line and the repair sections. For example, at times the flight line has not been able to find the reported malfunction. Therefore, they sign it off as "could not duplicate" (CND). If several CNDs show up on the historical report, the analysis section must alert the supervisor to a malfunction that is not being repaired. Another example: the flight line repairs the aircraft by replacing a component, but shop personnel CND the removed component that was replaced. If this component has a history of failures, it should be more closely analyzed to find the problem.

Exercises (280):

1. Why is the supervisor interested in the time taken to accomplish a task?

2. Some mechanics from your shop have worked all night at a troubleshooting problem without locating the trouble. Your supervisor, after consulting some maintenance records, quickly solves the problem. Which records did he probably consult?

3. Which section alerts the shop supervisor when the record shows that a malfunction is not being repaired properly?

281. State reasons for supervising instrument personnel.

Supervision. Active supervision of instrument personnel is essential for mission completion and for personnel safety. All supervisory activity should be directed toward accomplishing the mission. The goal of every job is its timely, correct, and safe completion.

It is also your responsibility when you are a supervisor to insure the safety of your people, yourself, and your coworkers. You must know the safe way to do the work, and they must know and do their work in a safe manner. Injury to a worker hampers or prevents mission completion. Their violations of safety procedures reflect upon you as their supervisor.

The kind of supervision you provide can affect the welfare of the worker. If you put your workers or trainees on jobs and forget them, they tend to feel that you don't care what they do. This results in carelessness and poor work, which in turn may lead to incomplete or aborted missions. Oversupervision produces equally bad results. Your people begin to think you don't trust them, thus causing a decrease in their initiative and support.

Exercises (281):

1. Why is active supervision of instrument personnel necessary?

2. State the supervisory goal of every job.

3. State how lax supervision affects the personnel and mission of a shop.

4. State the results of oversupervision.

282. State how supervisors and other personnel prepare for contingencies.

Contingency Plans. Air Force commands have contingency plans which state what is to be done if certain things happen or certain conditions exist. Included in these contingency plans are mobility plans. The mission of the command and the mission of the base must be accomplished even in time of war or when a natural disaster threatens. The structure of contingency plans is determined primarily by the mission of the command and the base. As a member of the Air Force and a future supervisor, you should know something about such plans.

A mobility plan is a time-scheduled sequence of events which is required for a maintenance shop to: (1) stop operations at one base, (2) move to another base, and (3) get back into operation in the shortest possible time. The plan schedules the movement of aircraft, support equipment, supplies, and personnel. It usually includes a list of essential parts (bits and pieces), essential end items, test equipment, ground equipment, and tools that must be moved for your shop to operate at the new location until normal supply channels can be set up. The material is packaged and placed in mobility kits, sometimes called flyaway kits, so that it is ready to be moved.

The shop supervisor must inventory and update the contents of these kits periodically to be sure that they will support the mission if required. If you are designated as a member of a mobility team, you too should know what is in the kits and how the various items are identified. When the alert sounds, it is too late to find out that you need something which is not in the kits. If it is your job to load your kits on the aircraft, there may not be time for you to find the kits and everything that must be moved. Because your supervisors and maybe even you are directly involved in developing these plans, they are tailored to fit your specific maintenance activity.

The squadron mobility activity is responsible for the development and implementation of the mobility plan. Its goal is to maintain the necessary readiness for the orderly and timely implemenatations of the plan. Your part, if you are a supervisor, is to keep the squadron appraised of the ability of your section to react to the plan. You do this by:

a. Identifying the personnel and equipment needed to meet the requirements of the mobility activity.

b. Informing the mobility activity of any personnel and equipment status changes.

c. Informing the mobility activity of any limiting factors.

d. Participating in the evaluation of test exercises.

e. Distributing flow plans.

f. Advising Maintenance Control of the start, completion, or progress made in carrying out the plan.

g. g. Advising Maintenance Control of any condition that may disrupt the orderly controlled execution of the plan.

h. Developing procedures to insure readiness and responsiveness.

i. Insuring that equipment is properly marked and packaged.

j. Insuring that personnel are properly trained.

If you are not a supervisor but are a mobility team member, you would participate in testing the plans during exercises, notifying your supervisor of difficulties encountered during the exercise, and using the plans if ever required.

Check with your shop chief and learn all you can about mobility plans. The plans for your current assignment will be different from the ones at your last assignment.

Exercises (282):

1. Name two factors that determine the structure of a mobility plan.

2. Name the activity that is responsible for the development and implementation of the mobility plan.

3. What part does a shop supervisor play in keeping the mobility plan current?

4. If an end-item that is part of a flyaway kit needs modification, what must the shop supervisor do?

Aircraft Familiarization, Hardware, and Tools

AS AN Avionics Instrument System Specialist, you know that the maintenance of instruments and related equipment is the major part of your job. In order to do your job as efficiently and proficiently as possible, you not only need to know how instrument systems operate, but you must understand how the related systems operate. For this reason, you need to have a good working knowledge of aircraft and their different systems.

There are several hundred types and models of aircraft that people in your career field are tasked to maintain. They range from huge cargo and bomber aircraft to small single-seat observation, trainer, and fighter aircraft.

In this chapter, you will become familiar with some of the general concepts of aviation and aircraft configuration and maintenance. We will cover the different types of military aircraft, their distinguishing characteristics, their similarities, and the hardware and tools required to maintain them.

5-1. Basics of flight

You cannot understand the hows and whys of the different instruments systems until you know the basics of flight. The flight controls of an aircraft, its axes, the forces controlling flight, and factors affecting aircraft flight are all part of the background knowledge you need.

283. State relationships between aircraft axes, control surface movements, and the controlling device.

Aircraft Axes. There are three axes around which the aircraft rotates and three flight controls which control this rotation. Figure 5-1 shows them to be the lateral axis, longitudinal axis, and vertical axis. The external flight controls that regulate movement around these axes are the elevator, ailerons, and rudder. The first two are actuated by the control stick or control column and wheel, depending upon the type of aircraft. The rudder is controlled by the rudder pedals.

Lateral axis. The lateral axis is also referred to as the pitch or Y axis. It is an imaginary line which runs from wingtip to wingtip through the center of gravity perpendicular to the fuselage centerline. Rotation around this axis is called pitch and is controlled by the elevators as shown in figure 5-1.

In straight and level flight, when forward pressure is applied to the stick or control column, the elevators move down and the aircraft responds by descending or diving. The elevators and other control surfaces are shown in figure 5-2. When the stick or control column is pulled back, the elevators move up, causing the aircraft to climb.

Longitudinal axis. The longitudinal axis is also known as the roll or X axis. It is an imaginary line which runs through the center of gravity from nose to tail along the fuselage centerline. It is perpendicular to the lateral and vertical axes. Rotation about this axis is called roll (see fig. 5-1) and is controlled by the ailerons (see fig. 5-2).

Moving the control stick toward a wing raises that wing's aileron, which causes the wing to go down and the aircraft to roll in that direction. At the same time, the other wing's aileron goes down which causes the wing to rise. Rotation about the longitudinal axis is in the same direction as the stick or control column movement.

Vertical axis. The vertical axis too, has other names. It is also called the yaw or Z axis. It is an imaginary line through the center of gravity, perpendicular to the lateral axis and the fuselage center line. Rotation about this axis is called yaw (see fig. 5-1) and is controlled by the rudder (see fig. 5-2).

When pressure is applied to the right rudder pedal in flight, the nose yaws to the right because the rudder has moved to the right, causing the tail of the aircraft to move to the left. When pressure is applied to the left rudder pedal, the rudder moves left and the tail of the aircraft is pushed to the right, which causes the nose to yaw to the left.

Exercises (283):

1. State the three axes of an aircraft.

2. Aft pressure on the control stick or wheel will cause response of what control surface(s)?

3. State the aircraft response to the situation in question 2.

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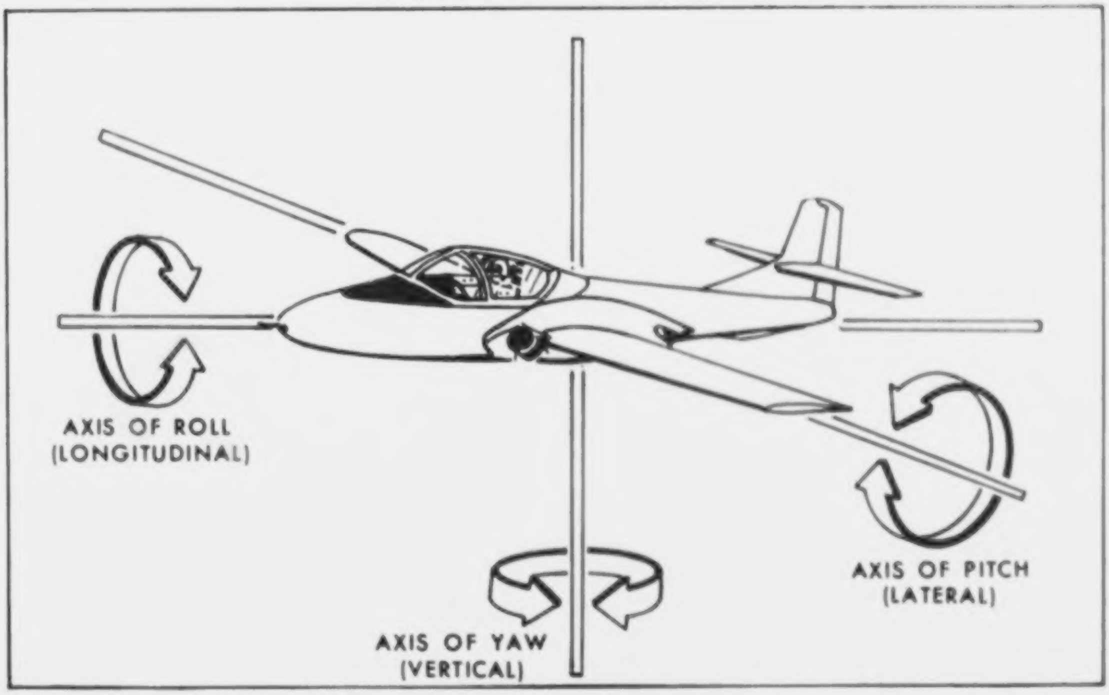

Figure 5–1. Axes of an aircraft.

4. Which cockpit control movement will produce a left (wing down) bank?

5. How will the flight control surfaces respond in question 4?

6. Which rudder pedal is pushed (pressure applied) to make the aircraft yaw right?

7. The control column or control stick has authority over which flight control surfaces?

284. Identify the forces that act upon an aircraft in flight and state their relationship to each other.

Forces Acting on an Aircraft. The four forces which act along the longitudinal and vertical axes of an aircraft are depicted in figure 5-3. They are lift, gravity, thrust, and drag.

Lift. A balloon rises because the weight of the air it displaces is greater than the weight of the balloon. A steel ship floats because the weight of the water it displaces is greater than the weight of the ship. The amount of force (lift) that keeps the balloon aloft or the ship afloat is the difference in weight between the balloon and the displaced air or the difference in weight between the ship and the displaced water.

Even though the airplane displaces a great amount of air, the airplane requires a source of power to set it in motion before it can leave the ground. This forward motion and the manner in which the wings deflect the air through which they move produce a lifting force. This lifting force can be demonstrated simply with a pencil and a sheet of paper. Coil a few turns of one edge of the paper around the pencil and let the other end hang free. Blow over the top of the paper. What happens to the free end of the paper? The upward movement of the paper is based on the law which states that as the velocity of the air over a surface is increased, the pressure decreases. As a result of this decrease in pressure over the top of the paper, an upward force is created. Likewise, a decrease in pressure with an increase in velocity can also be demonstrated with a spool, a pin, and a small circular piece of cardboard. Push the pin through the center of the cardboard and insert the end of the pin into the hole through the center of the spool. Blow into the opposite end of the spool. What happens to the cardboard? The harder you blow, the greater is the velocity of the air moving outward between the cardboard and the end of the spool. Therefore, the air pressure between the

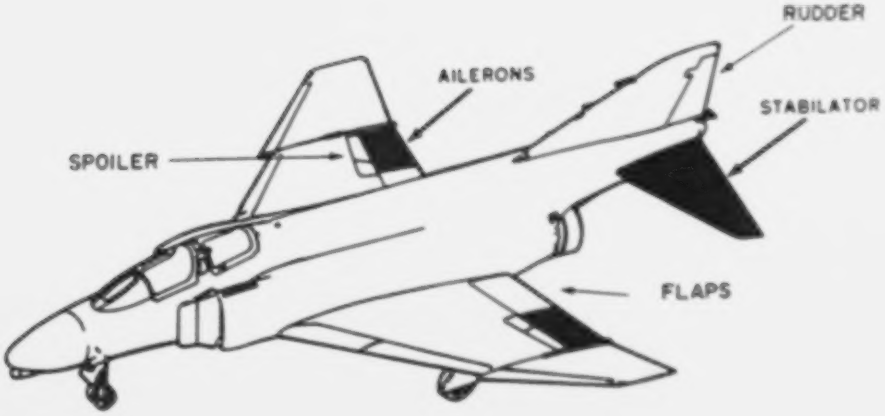

Figure 5-2. Flight control surfaces.

cardboard and spool is much less than the air pressure on the outside of the cardboard. That is why the cardboard moves closer to the spool as you blow through the hole in the spool.

Let's see how this principle applies to the airplane wing. The wing is designed so that air flows over the top of the wing faster than it flows under the wing. Therefore, according to the principle demonstrated above, the air pressure is less on top of the wing than on the bottom. This difference in pressure creates the upward force called lift. Note the cross section of the wing tip in figure 5-4 to see why air flows over the top of the wing faster than under the bottom. First, observe the shape of the wing. The top is curved more than the bottom. The leading edge is rounded, but the trailing edge tapers almost to a thin line. Secondly, the wing is inclined slightly in relation to the airstream. As the air strikes the leading edge, it divides, some going over the top and some going under the bottom. The air flowing over the top of the wing is deflected more than the air flowing under the wing. Therefore, the air moving over the top of the wing has farther to go to reach the trailing edge than the air moving under the wing. However, it must travel this greater distance in the same length of time as it takes the air moving under the wing to reach the trailing edge. Therefore, it must travel faster. Thus, by causing the air to move faster over the top of the wing than under the bottom, lift is created.

Thrust. In order for the aircraft to get the motion required for lift, another force is required. This force is called thrust. The thrust comes from the power plant, which may be a reciprocating engine with propellers, a jet engine, or a rocket engine. Whatever the type, the power plant transmits its thrust along the longitudinal axis to cause a forward velocity that we refer to as airspeed.

Drag. During flight, the power output of the engine—thrust—is opposed by drag. The force of drag is exerted upon an aircraft only during flight. It is set up by friction and turbulence of the air when the air meets and passes over and about the aircraft and its parts.

Total drag is the sum of induced drag, parasite drag, and profile drag.

a. Profile drag results from skin friction and the shape of the lifting surfaces (wings) of the aircraft. It does not include parasite drag.

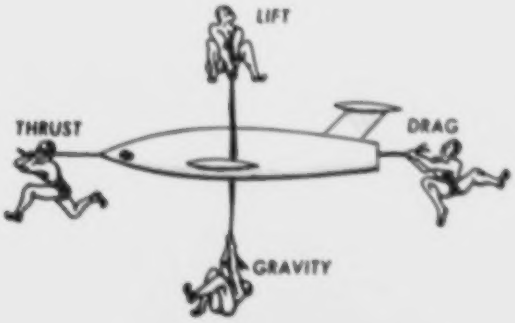

Figure 5-3. Aerodynamic forces.

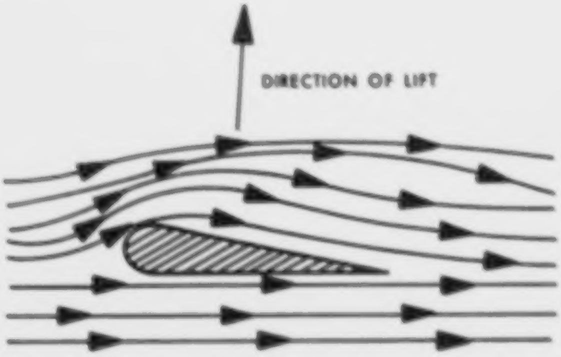

Figure 5-4. Airstream around a moving wing.

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b. Parasite drag is that part of the total drag caused by the skin friction and shape of the nonlifting surfaces of an aircraft, such as the fuselage, nacelles, cooling ducts, antennas, pitot tubes, angle of attack probes, etc. It is sometimes called structural drag.

c. Induced drag is that part of the total drag induced by the airflow about the lifting surfaces. The airflow that causes lift causes drag in proportion to the square of the lift.

d. Skin friction. The flow of air over any surface produces friction. Wind burn, a skin irritation caused by the wind, is a direct result of the friction produced by the flow of air over the skin. Whether we speak of humans or aircraft, the results of this friction can be serious. As an aircraft attains speeds in the 800-to-1400 mph range, the friction produces extreme and unbearable temperatures. To reduce the effects of this friction, aircraft surfaces are kept as smooth and clean as possible. In addition to the heat, the drag created by improperly installed components and panels on the exterior of an aircraft is sufficient to rip them away from the aircraft.

Gravity. The one force with which we are all most familiar is gravity. It is the force that attracts bodies toward the center of the earth and gives everything weight. It is not necessary for us to study Newton's laws of gravity at this time; just remember that gravity is always at work trying to keep the aircraft on the ground or to pull it back to earth once it is airborne. Gravity opposes lift just as drag opposes thrust.

Exercises (284):

1. List the forces that act upon an aircraft in flight.

2. Which force must be increased to overcome the additional drag created by ice on the wings?

3. Theoretically, as fuel is consumed during flight, which force(s) will change?

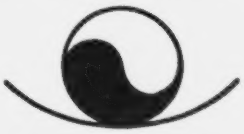
4. What types of drag make up total drag?

285. State how various types of stability act upon an aircraft.

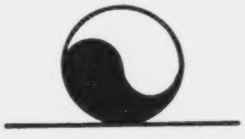
Aircraft Stability. Stability is divided into two major categories: static and dynamic.

Static stability. Static stability refers to the tendency of a system to react at the moment an unbalanced force or disturbance is removed. The three types of static stability are called positive, neutral, and negative. Each of these types is illustrated in figure 5-5. A body at rest possesses positive static stability if, when disturbed, it tends to return to its original position. If a body comes to rest in a new position after being disturbed, it possesses neutral static stability. If a body is disturbed at rest and then continues to move away from its initial position, it possesses negative stability.

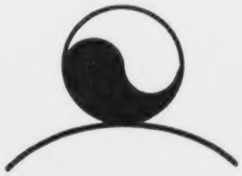
Dynamic stability. Dynamic stability is a term not often thoroughly understood in relation to aircraft. A positive form of stability is the desired condition of flight. When the aircraft is flying straight and level, it will remain there until disturbed; in other words, it will tend to fly without anyone manipulating the controls. If a gust of air disturbs the path of flight, the aircraft sets up counterforces to return it to level flight without control manipulation. Negative stability would exist when the aircraft, upon being disturbed from level flight, would continue to alter its flightpath in the manner started. To right the aircraft requires manipulation of the controls. If even slightly overcontrolled, the aircraft would dart in the opposite direction, requiring constant movement of the controls to maintain level flight. Neutral stability exists when the aircraft, after being disturbed from its flightpath, assumes a new position, neither returning to its original path nor continuing to depart further from it.



POSITIVE STABILITY



NEUTRAL STABILITY



NEGATIVE STABILITY

Figure 5-5. Types of static stability.

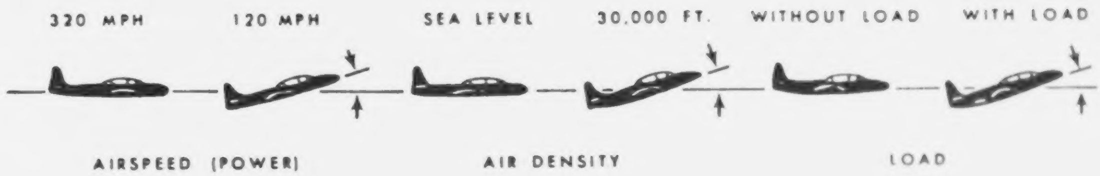


Figure 5-6. Factors affecting straight and level flight.

Exercises (285):

1. How is a body affected by negative static stability?

2. What are the major categories of aircraft stability?

3. What type of static stability is possessed by a body if, when disturbed, the body comes to rest in a new position?

4. What form of dynamic stability, in relation to aircraft, is the desired condition of flight?

286. State how an aircraft will react to specified changes in factors controlling straight and level flight.

Factors Affecting Straight and Level Flight. Illustrated in figure 5-6 are three factors that affect straight and level flight: airspeed (power), air density, and load (weight). Each of these factors is dependent upon the others. Airspeed depends on air density and weight, and air density plays a big part in load and airspeed.

Airspeed. At low speeds the angle of attack of an airfoil must be relatively large to produce the lift necessary to maintain level flight; and as a result, the aircraft must be flown in a nosehigh attitude. As power is increased and the aircraft accelerates, the nose must be lowered because the angle of attack necessary to produce sufficient lift to maintain level flight will become less. Any change in airspeed requires a change in attitude to maintain straight and level flight.

Air density. The density of the air decreases with increases in either altitude or air temperature. To maintain a given amount of lift, the angle of attack of an airfoil must be increased as the density of the air decreases. Therefore, in order to maintain level flight at high altitudes or in regions of very warm free-air temperature, the attitude of the aircraft must be relatively nose high.

Weight of the aircraft (load). At normal weight, an aircraft requires a definite angle of attack to maintain straight and level flight at a given airspeed. However, to sustain a heavier load at the same airspeed, the angle of attack of the airfoil must be greater to provide increased lift. If the same airspeed is to be maintained, the power must be increased to overcome the increased drag which results from the increased angle of attack. For example, at the start of a bombing mission, an aircraft must be flown in a slightly nose-high attitude in order to maintain level flight. As the bomb load and fuel are expended, the nose of the aircraft must be lowered to maintain level flight.

Exercises (286):

1. What change to the aircraft must be made when the airspeed is reduced?

2. At a specified airspeed, which would require the higher angle of attack, 3,000 foot altitude or 25,000 foot altitude? Why?

3. If a bomb load requires a specific angle of attack to maintain straight and level flight, how must that angle be changed when the bomb load is dropped?

287. State how the forces that act upon an aircraft change during specified maneuvers.

Aircraft Maneuvers. The basic maneuvers that we will discuss include climbs, descents, and turns.

Climbs. For all practical purposes, the lift in normal climbs is the same as in straight and level flight at the same airspeed. The angle of attack of the airfoil with respect to the flightpath of the aircraft remains the same regardless of any variation of the flightpath from the horizontal. To go from straight and level flight to a definite change in attitude, the first change, lift, occurs when backpressure is applied to the controls. The change in lift is a result of the change in the angle of attack when the nose is raised.

Momentarily, the lift, which becomes greater than the weight of the aircraft, forces the craft to a higher attitude. The flightpath is then inclined upward and, as a result, the angle of attack and the corresponding lift again stabilize.

As the climb is started, the airspeed gradually decreases. This change in airspeed is gradual rather than immediate because of the momentum of the aircraft. The thrust required for a given airspeed in straight and level flight is not sufficient to maintain that airspeed in a climb. This is due to a component of weight acting in the same direction and parallel to the total drag of the aircraft so that thrust must equal the total drag of the aircraft plus the added component of weight. Therefore, as the aircraft enters a climb, and power remains constant, the airspeed will decrease. The reduction in airspeed causes a reduction in drag. When drag is reduced to the point where the total drag and the component of weight acting in the same direction are equal to the thrust, the aircraft climbs at an airspeed slower than the cruising airspeed.

To go from level flight into a climb at the same airspeed, the pilot must increase the power output of the engine (thrust). This is necessary because of the additional thrust necessary to overcome the component of weight acting in the same direction and parallel to the total drag of the aircraft.

Lift is equal in magnitude to the component of weight that is perpendicular to the flightpath. In a climb, a component of weight acts to the rear and parallel to the total drag of the aircraft, and is balanced by part of the thrust. For normal rates of climb, this component of weight is very small since the angle of attack changes very little. This is important for aircraft that climb at large angles of attack.

Descents. As in a climb, the forces acting on the aircraft go through definite changes when the aircraft starts a descent from straight and level flight. When forward pressure is applied to the controls, the angle of attack is reduced and, as a result, the lift of the airfoil is reduced. This reduction in lift is momentary as the flightpath of the aircraft changes and the angle of attack resumes the value of straight and level, as in a climbing flight. The change in flightpaths is due to the lift's becoming less than the weight of the aircraft as the angle of attack is reduced. This unbalance of lift and weight causes the aircraft to follow a descending flightpath with respect to the horizontal flightpath of straight and level flight. As the flightpath changes to a descent, the angle of attack of the airfoil again approaches the original value, and lift and weight stabilize. As the descent is started, the airspeed gradually increases due to a component of weight now acting forward along the flightpath. The overall effect is increased power or thrust, which, in turn, causes the increase in airspeed associated with descending at the same power as used in level flight. For descents at the same airspeed as used in straight and level flight, the power must be reduced as the descent begins. The component of weight acting forward along the flightpath increases as the rate of descent increases; conversely, it decreases as the rate of descent decreases. The amount of power reduction for a descent at the same speed as cruise is determined by the rate of descent required.

Turns. If a pilot understands the forces acting on an aircraft in a turn and knows how to bring these forces to bear upon the aircraft, he or she should have no difficulty with directional control. Misconceptions as to the manner in which an aircraft is turned have been partially responsible for the faulty manner in which instrument flying has been taught. If an aircraft could be observed in straight and level flight from a head-on view, and if the forces acting on the aircraft could be seen, two forces, lift and weight, would be apparent; and if the aircraft were in a bank, it would be apparent that lift did not act opposite to the weight. The fact that lift acts inward toward the center of the turn as well as upward is one of the basic facts to remember in the consideration of turns.

An aircraft, like any moving object, requires a side force to make it turn. In a normal turn, this force is supplied by banking the aircraft so that lift is exerted inward as well as upward. The force of lift in a turn is separated into two components at right angles to each other. One component, which is drawn vertically and opposite to weight, is called the vertical component of lift. The other, which is drawn horizontally toward the center of the turn, is called the horizontal component of lift.

The horizontal component of lift is the force that causes the aircraft to turn. Centrifugal force is the equal and opposite reaction of the aircraft to the change in direction and is equal and opposite to the horizontal component of lift, as illustrated in figure 5-7. In a correctly executed turn, the force to turn the aircraft is not supplied by the rudder. An aircraft is not steered like a boat or an automobile; in order to turn, it must be banked. If the aircraft is not banked, there is no force available that will cause it to deviate from a straight flightpath, provided it is not skidding. Conversely, when an aircraft is banked, it will turn provided it is not slipping. Good directional control is based on the fact that the aircraft will turn if banked. This fact should be borne in mind at all times while attempting to hold the aircraft straight and level by reference to instruments. An indication of a bank from the flight instruments should immediately be corrected by a roll-out of the bank in order to maintain the desired heading and flightpath.

Banking the aircraft in order to turn produces no change in the amount of lift. In a bank, however, the lift is divided into two components, one vertical and the other horizontal. This division reduces the amount of lift that is supporting the weight of the aircraft; consequently, the aircraft loses altitude unless the total lift is increased by increasing the angle of attack until the vertical component of lift is equal to the weight. The vertical component of lift decreases as the angle of bank is increased; as a result, the angle of attack must be increased as the angle of bank is increased in order to produce sufficient vertical lift to support the weight of the aircraft. The fact that the vertical component of lift must be equal to the weight for a correctly executed level turn is an important fact to remember.

Slips and skids. An aircraft points directly along its flightpath, except when it is slipping and skidding. The aircraft may be yawed to either side of the flightpath by use of the rudder or by an incorrect adjustment of the rudder trim tab. The same yawing effect can be caused by the

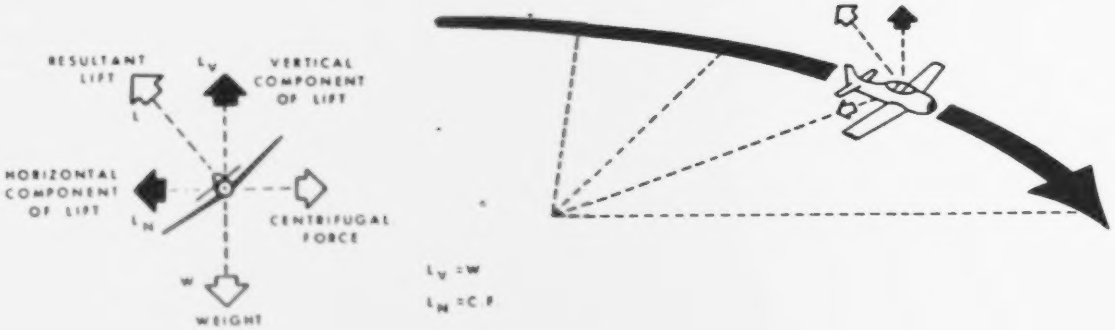


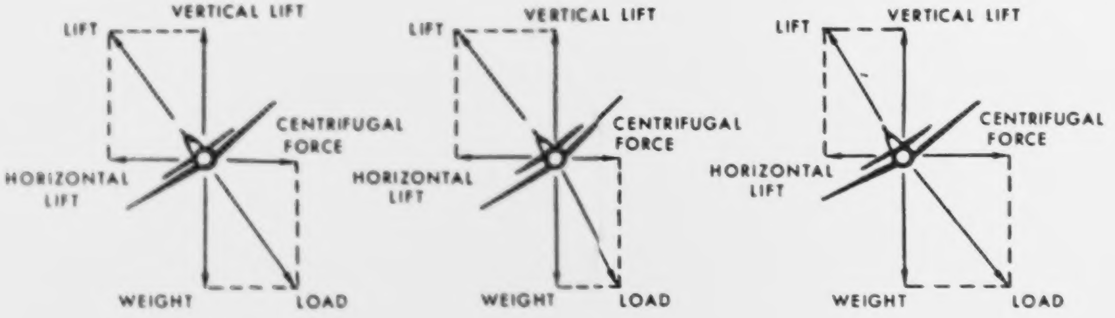
Figure 5-7. Forces acting on an aircraft in a normal turn.

ailerons. If one aileron is deflected slightly downward and the other is aligned properly, the maladjusted aileron causes more drag on that side of the aircraft. In a correctly trimmed aircraft, directional stability of the aircraft plays an important part in returning the aircraft to its proper position in straight and level flight after a slip or skid.

You should understand the reasons for an aircraft slipping during turns. A slip in a turn is similar to a slip in straight flight; the aircraft is not allowed to turn at a rate proper for the angle of bank. In a slipping turn, the rate of turn is not great enough for the angle of bank. The aircraft is not allowed to head directly along its turning flightpath, but is yawed to the outside of the path followed in the turn. The yaw may be the result of top rudder pressure, or, in some aircraft, drag of the top aileron on entering the turn. A slip in a turn is indicated by the displacement of the ball in the turn and bank indicator to the inside of the turn or in the direction of the bank. This indication is a result of the aircraft's being banked too much for the rate of turn, so the resultant gravity and centrifugal force acts downward. In the first two views of figure 5-8, view number 1 shows an aircraft turning at the proper rate for the angle of bank, and view number two shows an aircraft turning less than is proper for the angle of bank.

Skidding turns. In a skidding turn, the rate of turn is too great for the amount of bank. At a given rate of turn with an insufficient amount of bank, the centrifugal force and weight force produce a resultant that is not equal and opposite to the lift. The resultant acts toward the outside of the turn with respect to the direction of the force of lift. The skid carries the aircraft outside the desired flightpath and away from the direction of turn. Aircraft skidding is indicated by the displacement of the ball in the turn and bank indicator to the outside of the turn. A skidding turn can be corrected by reducing the rate of turn and holding the same angle of bank or by increasing the angle of bank and holding the rate of turn constant. The third view, figure 5-8, shows an aircraft in a skidding turn. Compare this view with the normal and slipping turns shown in view no. 1 and view no. 2.

Coordinated use of rudder and ailerons in turns. Most aircraft may be turned by use of either ailerons or rudder. However, if the aircraft is turned by the ailerons only, it tends to slip, because the outside aileron causes more drag than the inside aileron. The amount of slipping depends upon the violence with which the controls are used, since the more the ailerons are moved out of a neutral position, the greater is the yawing effect on the aileron drag. If the ailerons are used more slowly, the slipping is negligible.



1. NORMAL TURN. CENTRIFUGAL FORCE EQUALS HORIZONTAL LIFT.

2. SLIPPING TURN. CENTRIFUGAL FORCE LESS THAN HORIZONTAL LIFT.

3. SKIDDING TURN. CENTRIFUGAL FORCE GREATER THAN HORIZONTAL LIFT.

Figure 5-8. Action of forces in a turn.

An aircraft turned by the use of the rudder only is yawed toward the inside of the turn, and the lift of the outside wing is increased to a value greater than the lift of the inside wing. At best, the effect of the rudder is slow, and if the rudder is used with any force, considerable skidding accompanies the increase in angle of bank. It is difficult to turn an aircraft flying at high speed by the use of rudder alone, because the yawing effects of the rudder do not materially increase the lift of the outside wing. In high-speed aircraft, the radius of the turn is so great that the increase in the speed of the outside wing over that of the inside wing is extremely small and has little effect on the relative lift of both wings.

An aircraft is correctly turned only by the coordinated use of the rudder and the ailerons. The relative use of these two controls is determined by the characteristics of the particular aircraft and the airspeed at which the maneuver is executed. The indications of the needle and ball instrument provide an accurate gage for determining the correct use of these controls. After the aircraft has been banked for a turn, the angle of bank should be held constant without skidding or slipping. This requires some adjustment of both ailerons and rudder pressure, and depends on the characteristics of the aircraft and its speed.

Exercises (287):

1. When an aircraft enters a climb, what happens to the angle of attack with respect to the aircraft flightpath?

2. Explain why the thrust required for a given airspeed in straight and level flight is insufficient to maintain that airspeed in a climb?

3. When an aircraft enters a descent at the same airspeed as used in straight and level flight, why does the airspeed increase?

4. What is the direction of the lift force when an aircraft enters a turn?

5. Identify the components of lift in a turn.

6. State why an aircraft normally loses altitude in a turn unless corrected for, and how the correction is made.

7. What can be done to increase the aircraft horizontal component of lift in a turn?

8. Which way does the ball in the bank and turn indicator move when the aircraft is in a slip?

9. What causes an aircraft to slip during a turn?

10. What causes an aircraft to skid during a turn?

11. How is an aircraft turned correctly?

288. Identify the various types of aircraft and state distinguishing characteristics of specified types.

Aircraft Types. Today, each Air Force mission is highly specialized and requires a special type of aircraft and equipment. We will discuss the most common types.

Fighter aircraft. A fighter aircraft is a combat airplane designed primarily for intercepting and destroying other aircraft in the air. With both single-place and dual cockpit versions, the fighter aircraft is fast and maneuverable and is often used for escort and tactical operations. Most fighters carry heavy firepower and can perform at supersonic speeds. Their firepower may consist of rapid-fire machine guns, cannons, or rockets. See figure 5-9.

Bomber aircraft. A bomber aircraft is specifically designed to carry and drop bombs. To accomplish this mission successfully, bomber aircraft must be equipped with powerful engines capable of long missions at very high altitude. Bombers of today can refuel in flight to increase the range and mission length indefinitely. See figure 5-10.

Cargo aircraft. The cargo aircraft is designed with the fuselage (body) large enough to allow loading of heavy freight and military type vehicles. Just a few short years ago, cargo aircraft would be described as slow-flying, just the opposite of the fighter and bomber types. Now, jet- and turboprop-powered cargo aircraft can fly at very high speeds and altitudes. They possess the ability to carry heavy loads over long distances. (See fig. 5-11.)

Distinguishing Characteristics. Each of these types of aircraft have distinguishing characteristics that set them apart from the others.

Fighter. Most fighters are either single- or twin-engined with swept-back wings and horizontal and vertical stabilizers. The F4 aircraft shown in figure 5-9 has been in service for many years, but continues to play an important role.

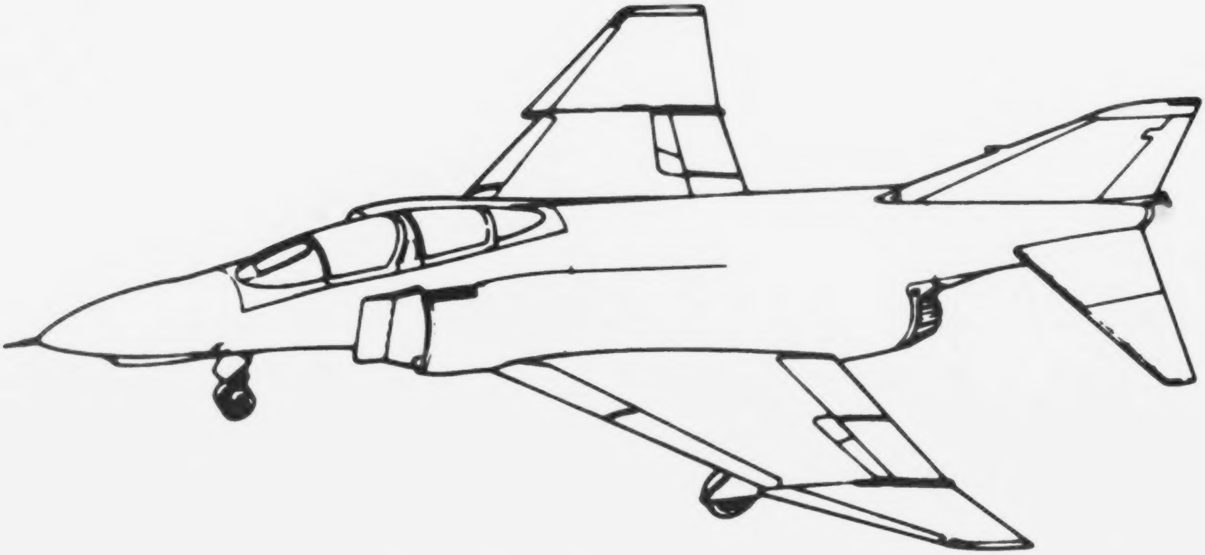


Figure 5-9. F-4 aircraft (fighter).

Bomber. The name, bomber, brings to mind the B-52 as shown in figure 5-10. Also in use for many years, continuous updating of equipment and systems allows this multiengined giant to continue in the inventory. It is identified by its high wing, eight engines, and tall tail.

Cargo. Today, the three main cargo type aircraft in use are the C-130, C-141, and C-5. Refer to figure 5-11, which shows the C-141. All cargo types can be identified by the rather large fuselage and by access to this cargo holding area via large doors either at the rear or front or both.

Exercises (288):

1. Name the predominate types of aircraft.

2. What are the design characteristics of fighter aircraft?

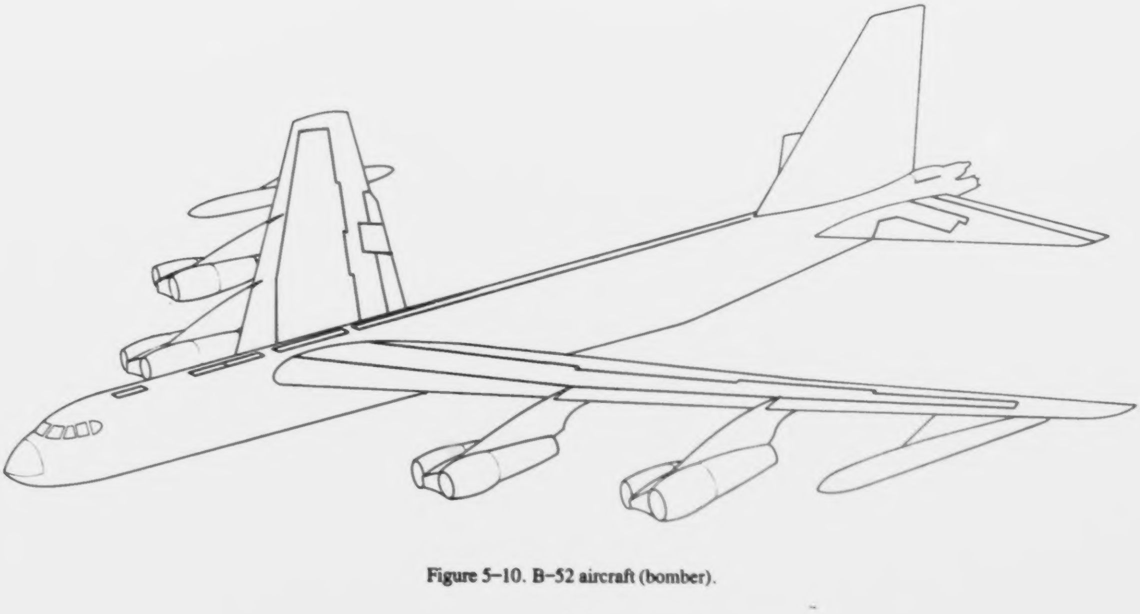


Figure 5-10. B-52 aircraft (bomber).

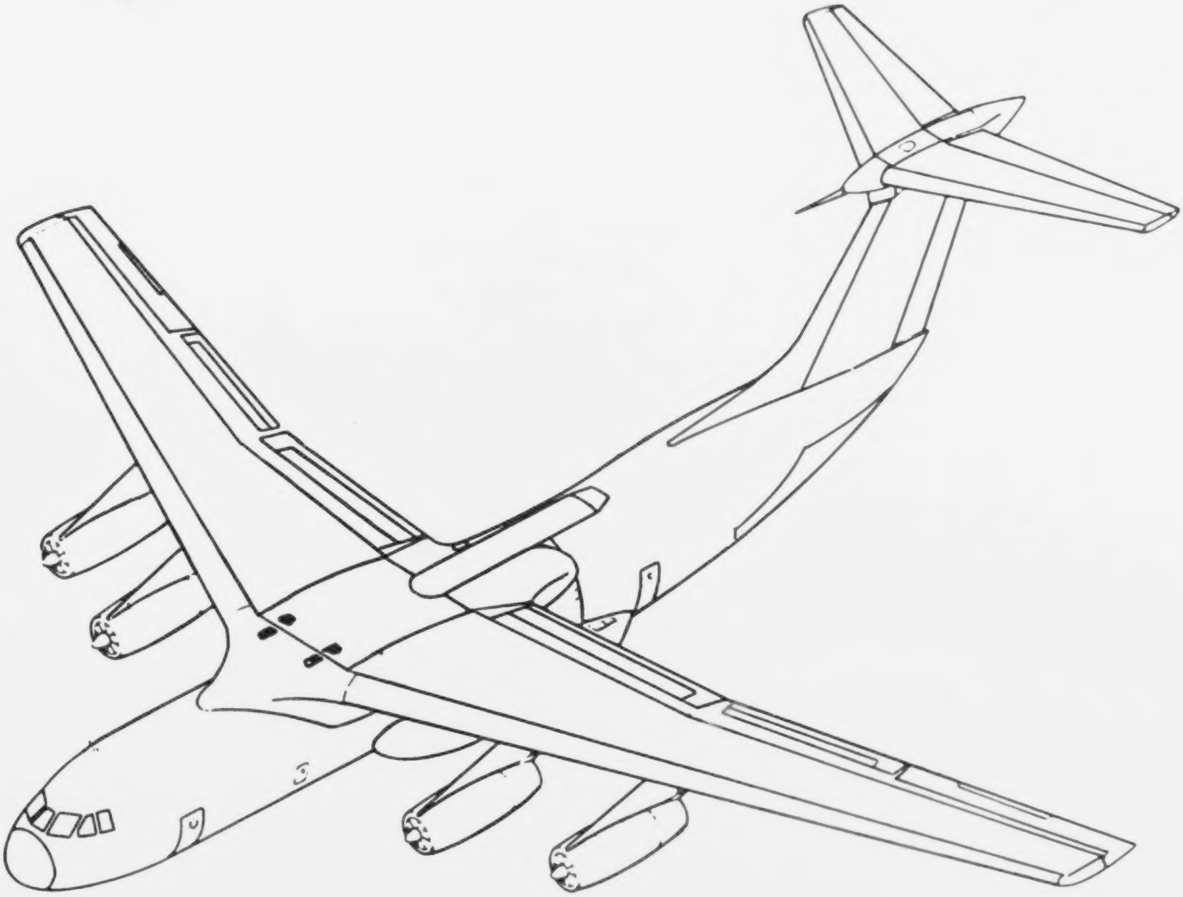


Figure 5–11. C141 aircraft (cargo).

3. Which of the aircraft types is capable of carrying heavy loads to faraway destinations?

4. What type of wings do most fighter aircraft possess?

289. State major structural areas of an aircraft and match components to their functions.

Aircraft Structural Areas. An aircraft contains many parts that are welded, riveted, bolted, or screwed together. Since these parts make up the structure of the aircraft, they are called structural members. These members are grouped into several areas. The fuselage, wings, and empennage are the principal structural areas of an aircraft.

Fuselage. The fuselage is the main structural area of an aircraft. It is the main body on which other structural units are directly or indirectly attached. From the standpoint of general design, the fuselage of one type of aircraft is much the same as any other. Many designs have been successfully tried for different Air Force needs. The best features are still used in the latest aircraft.

Wings. The wings are surfaces designed to give lifting force when moved through the air. The wing design for any given aircraft depends upon a number of factors. These are size, weight, use of the aircraft, desired speed in flight and at landing, and the desired rate of climb. The wings are designated as left and right, corresponding to the left and right hands of the pilot seated in the cockpit.

Certain features of the wing will cause other variations in its design. The tip may be square, rounded, or even pointed. Both the leading and trailing edges of the wing may be straight or curved. One or both edges may be tapered so that the wing is narrower at the tip than where it joins the fuselage.

In addition, the wing may contain, or have attached to it, engine nacelles or jet pods which hold the aircraft engines.

Empennage. The empennage is simply the tail section of the aircraft. It includes the aft end of the fuselage and the rudder, elevators, and stabilizers. Other parts of the empennage are the stabilizing units of the aircraft. These are the vertical and horizontal surfaces located on the rear portion of the aircraft. The vertical surface is called the vertical stabilizer. The horizontal surface is called the horizontal stabilizer.

Exercises (289):

1. Identify the three principal structural areas of an aircraft.

2. Match the structural areas below with their functions.

Column A	*Column B*
____ (1) Fuselage.	a. Give lifting force.
____ (2) Wings.	b. Stabilizing units.
____ (3) Empennage.	c. Main structural unit.

290. State the purposes of the station numbering system.

Station Number System. The station numbering system provides maintenance personnel with a three-dimensional location system to find parts and components on the aircraft. To accomplish this, the station numbering system uses body (fuselage) station numbers, body buttock lines, wing station lines, and water line references. Station call-outs are theoretical reference planes established throughout an aircraft that establish its configuration.

Body (Fuselage) station numbers. Body station numbers, on some aircraft referred to as fuselage station numbers, are measured from a designated point near the nose of the aircraft along the longitudinal centerline of the fuselage. This point is referred to as station zero (0). For example, on the F–4, the zero reference point (0.00) is located behind the forward tip of the radome (see fig. 5-12), and all numbers forward of the zero reference are negative. They are positive and get progressively larger as you move to the rear of the aircraft. The station number tells you how many inches from the zero reference point a component is located.

The zero reference point will be in different places for different types of aircraft. For example, fuselage station 0.00 on the F–5 is an imaginary point in front of the actual tip of the aircraft nose (see fig. 5-13).

Wing stations. Wing stations (also called wing buttock lines) are also distances which are measured in inches. The reference point is the longitudinal centerline of the aircraft, which is wing station zero (0). Locations on the left of the centerline (WS 0.00) are indicated by the letter L, and those on the right by the letter R.

Water lines. Vertical fuselage reference stations (height references) are indicated by water line stations. Again, water lines are distances measured in inches from a specific reference point (WL 0.00), which may be the lowest part of the fuselage or an imaginary line running through both wing tips.

Body buttock lines. Body buttock lines are also imaginary lines along the fuselage of the aircraft. They, too, are measured left (L) and (R) from the fuselage centerline. They aid you in locating components or parts in the fuselage, whereas wing stations or wing buttock lines apply to the wing areas.

Consult the applicable dash two (–2), Organization Maintenance Technical Order, for the aircraft you are working on to find out what system and reference points are used.

Exercises (290):

1. What is the purpose of the aircraft station numbering system?

2. Name the elements used in station numbering systems.

3. What unit of measure is used by the station numbering system?

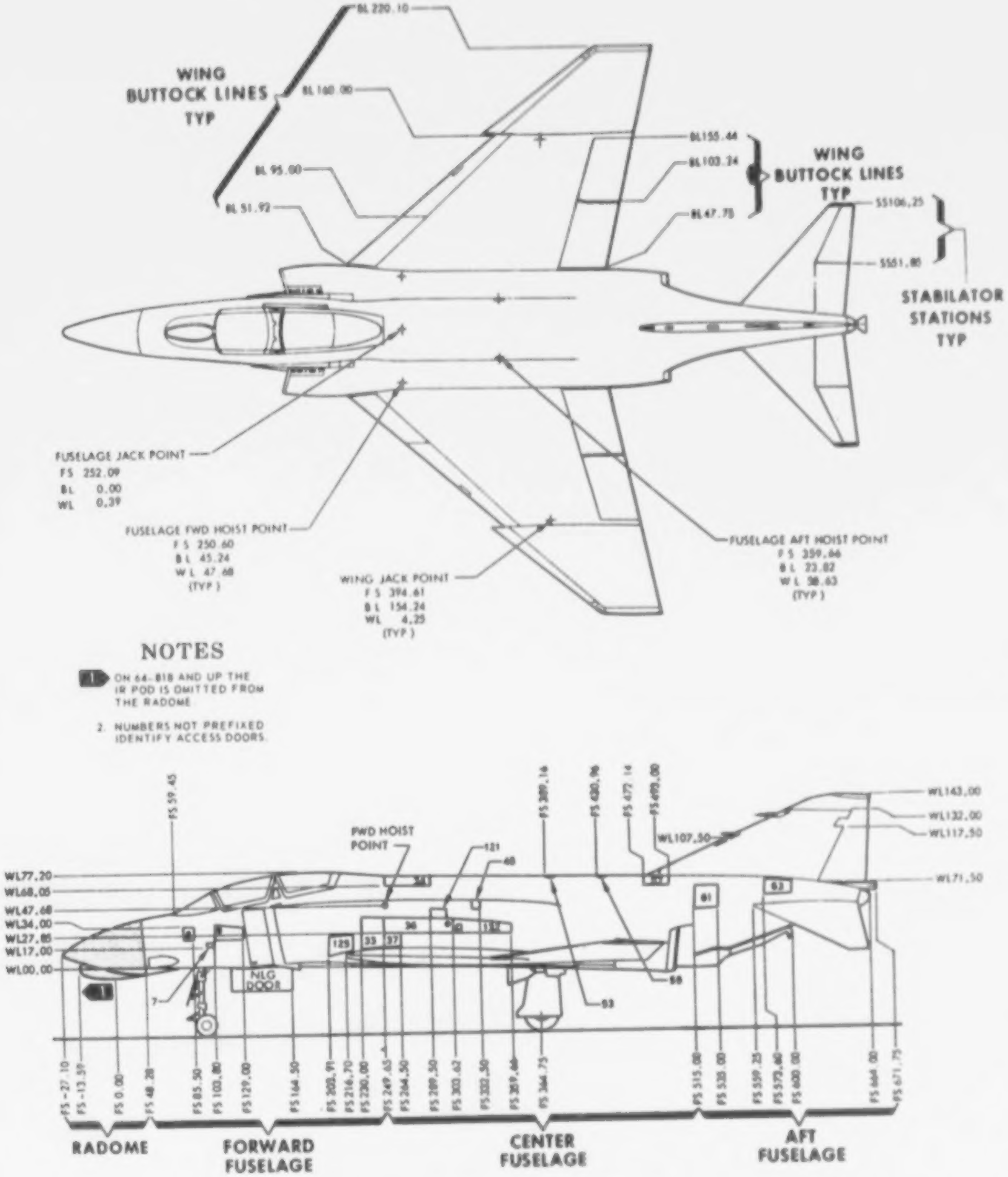
4. Where would wing station R88.36 be on the F–5 aircraft?

5. Where is water line 0.00 located?

6. What system is used to locate components in the wings of an aircraft?

5-2. Aircraft Hardware

When you have located the instrument, component, or part on the airframe, you still have to contend with the hardware used to mount and secure it. This means using the proper tools for the job so as not to injure yourself or someone else and not to damage the equipment or hardware in the process.


BL 220.10
WING
BUTTOCK LINES
TYP
BL 160.00
BL 95.60
BL 51.92
BL155.44
BL103.24
BL47.75
WING
BUTTOCK LINES
TYP
SS106.25
SS51.85
STABILATOR
STATIONS
TYP
FUSELAGE JACK POINT
FS 252.09
BL 0.00
WL 0.39
FUSELAGE FWD HOIST POINT
F S 250.60
B L 45.24
W L 47.68
(TYP)
WING JACK POINT
F S 394.61
B L 154.24
WL 4.25
(TYP)
FUSELAGE AFT HOIST POINT
F S 359.66
B L 23.82
W L 58.63
(TYP)
FS 59.45
FWD HOIST
POINT
121
48
FS 389.16
FS 430.96
FS 472.14
FS 493.00
WL107.50
WL143.00
WL132.00
WL117.50
WL71.50
WL77.20
WL68.05
WL47.68
WL34.00
WL27.85
WL17.00
WL00.00
1
7
NLG
DOOR
125
33
37
36
52
132
53
58
61
63
FS -27.10
FS -13.59
FS 0.00
FS 48.28
FS 85.50
FS 103.80
FS 129.00
FS 164.50
FS 203.91
FS 216.70
FS 230.00
FS 249.63
FS 264.50
FS 289.50
FS 303.62
FS 332.50
FS 359.66
FS 364.75
FS 515.00
FS 535.00
FS 559.25
FS 573.60
FS 600.00
FS 664.00
FS 671.75
RADOME
FORWARD
FUSELAGE
CENTER
FUSELAGE
AFT
FUSELAGE

NOTES

1 ON 64-818 AND UP THE IR POD IS OMITTED FROM THE RADOME

2. NUMBERS NOT PREFIXED IDENTIFY ACCESS DOORS.

Figure 5-12. F-5 station and line numbering.

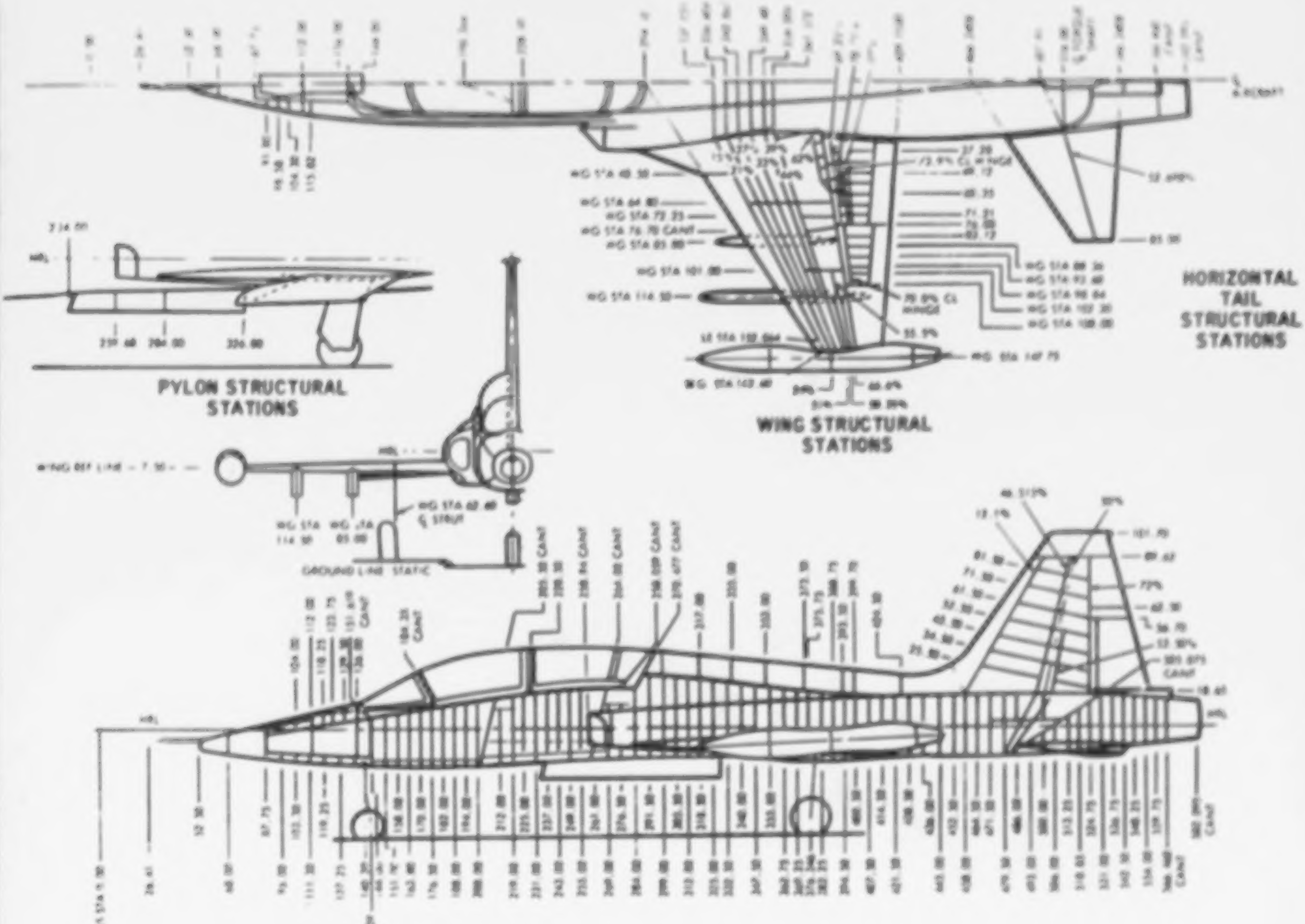

PYLON STRUCTURAL STATIONS
WING STRUCTURAL STATIONS
HORIZONTAL TAIL STRUCTURAL STATIONS
GROUND LINE STATIC
FUSELAGE STRUCTURAL STATIONS

Figure 5-13. F-4 stations and lines.

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291. Give reasons for using specific types of bolts in various aircraft applications, and identify the meanings of given bolthead markings.

As an Avionics Instrument Systems Specialist, you should know what type of nut, bolt, screw, or fitting to use. Using the wrong hardware can result in the premature failure of equipment or the destruction of an aircraft with a loss of life. The proper function of some parts and hardware depends upon its material strength and proper fit. When you replace parts or hardware, be certain it is of identical material and size.

Bolts. Bolts are used to fasten together parts of a mechanism or structure. They are most frequently used with a threaded nut, but there are exceptions. They are also used in tapped holes in a mechanism or structure.

Most bolts used in aircraft structures are general-purpose AN (Air Force–Navy Standard), NAS (National Aircraft Standard), internal wrenching, or close tolerance bolts. When the size and strength requirements demand special bolts, aircraft manufacturers make them. Since these bolts are made for a special purpose, they must be used when required. Such special purpose bolts are identified by the letter "S" stamped on the head. Head markings on other bolts may indicate the bolt type, its intended use, or the material from which it is made. Standard aircraft bolts are marked for identification as shown in figure 5-14. The head of a steel bolt is marked with an asterisk (*) or X. An aluminum alloy bolt has two opposed u-marks or straight lines on the head. Bolts are usually made of cadmium or of zinc-plated nickel-steel, dural, or an aluminum alloy.

The size of a bolt is stated in terms of length, diameter, and threads per inch. A bolt 2 inches in length, 1/4 inch in diameter, and having 28 threads per inch would be called a 2-inch bolt, 1/4 by 28. Bolts with a diameter of 1/4 or greater are specified by actual diameter measurement in inches or fractions of an inch. Bolts of less than 1/4 inch diameter are specified by a number; for example, size 12 is the next size smaller than 1/4.

Bolts are made in so many shapes and varieties that a clearly defined method of classification is difficult. For the sake of simplicity only, they may oe roughly classified according to the shape of the bolt head.

Hexhead. The hexhead is available in a drilled (for safety wire) or undrilled head. It is also available in thin heads for use in tight places. This type is used where heavy tension or lengthwise stresses must be sustained.

Clevis. The clevis bolt is a special purpose bolt for use where shearing or sideward stress occurs. Clevis bolts are never used for tension but are often used as pins in control systems. Clevis bolts are available with either slotted (for a screwdriver) or recessed heads.

Eyebolt. The eyebolt is a special purpose bolt used where external tension loads are applied. The eye is for attaching a turnbuckle fork, clevis shackle, or tiedown rope.

Internal wrenching. This bolt is made of high-strength steel and is used primarily in high tension applications such as on jet engines. The head is recessed for internal wrenching by Allen wrenches, bristol wrenches, or other wrenching devices.

Stud. The stud is used when a standard-type bolt is impractical, such as when mounting tachometer generators and other engine accessories.

Exercises (291):

1. For what are bolts used in instrument systems maintenance?

2. List four types of bolts used in aircraft maintenance.

3. Match the bolthead markings in column A with their meanings in column B. Some answers may be used more than once or not at all.

Column A	*Column B*
____ (1) *	a. Special purpose.
____ (2) u.	b. Close tolerance.
____ (3) X.	c. Aluminum alloy.
____ (4) Δ	d. Close tolerance steel.
____ (5) —	e. Corrosion resistent steel.
____ (6) S	f. Close tolerance aluminum.
	g. Steel.

292. Identify specific types of nuts used in aircraft maintenance, and give reasons for their use.

Nuts. Like bolts, nuts come in a wide variety of shapes, sizes, and materials. Aircraft nuts are not usually issued with the bolts and must be obtained separately. They are identified by color of metal and construction (style, size, etc.). Blue is used for aluminum, silver for stainless steel, etc.

Nuts are threaded internally to mate with the threads of a bolt, screw, or stud. It is most important that the mating threads be identical. If a bolt, screw, or stud has 28 threads per inch, the nut, too, must have 28 threads per inch. Except for a very few special types, nearly all nuts are standard and can be divided into two general groups: self-locking and non-self-locking.

Self-locking nuts. As their name implies, self-locking nuts lock themselves; the locking feature is built into the nut. They are designed to withstand severe vibration. They are not used at joints in control systems or mechanical linkages where the movement would cause the nut to work loose because of friction against the surface on which the nut is bearing. At least two threads must extend through a self-locking nut for maximum locking effect. Some self-locking nuts are intended for a one-time use; that is, they should be replaced and not reused.

Non-self locking nuts. These nuts must be secured by external locking devices such as locknuts, cotter pins, or more commonly, safety wire. Figure 5-15, shows several types of commonly used aircraft nuts.

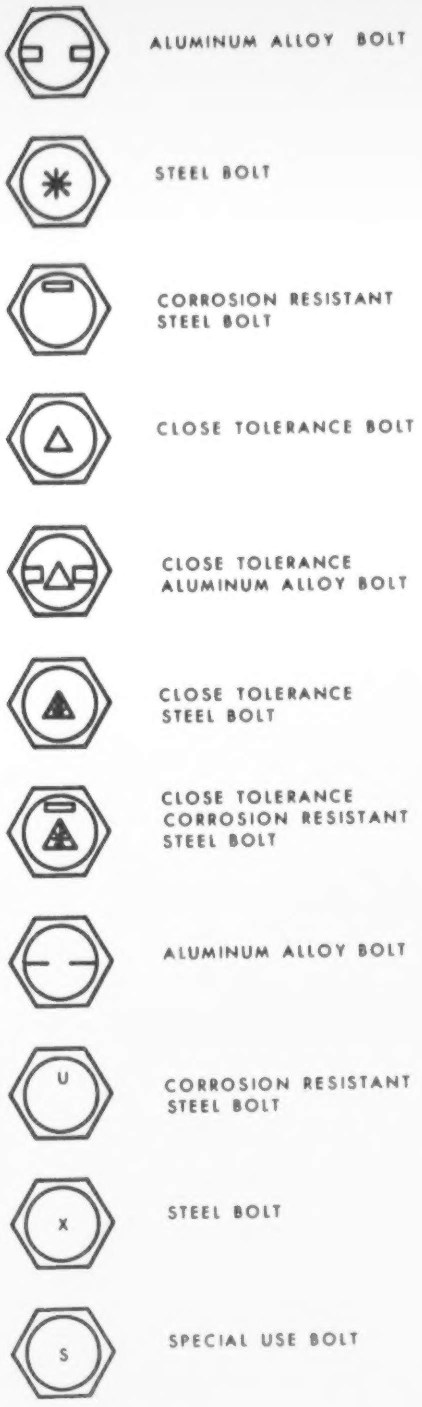

ALUMINUM ALLOY BOLT
STEEL BOLT
CORROSION RESISTANT STEEL BOLT
CLOSE TOLERANCE BOLT
CLOSE TOLERANCE ALUMINUM ALLOY BOLT
CLOSE TOLERANCE STEEL BOLT
CLOSE TOLERANCE CORROSION RESISTANT STEEL BOLT
ALUMINUM ALLOY BOLT
U
CORROSION RESISTANT STEEL BOLT
X
STEEL BOLT
S
SPECIAL USE BOLT

Figure 5-14. Bolt identification.

Plate nuts. As shown in the center of figure 5-15, plate nuts are used for blind mounting in unaccessible locations to make maintenance easier. You will frequently find them used to mount instruments. These will normally be self-locking, but non-self-locking plate nuts are available. Floating-type plate nuts allow a controlled amount of nut movement to compensate for misalignment. Because plate nuts are rivited to an aircraft structural member, sheet metal personnel will normally remove and replace them when necessary. Exercise care when using them so as to prevent unnecessary replacement of them.

Tinnerman nuts. These nuts (see fig. 5-16) are also often used to mount instruments, especially on the instrument panel. Sometimes called sheet spring nuts, they are available for standard screw sizes 6–32, 8–32, and 10–32. Normally installed in the instrument panel for front mounting of instruments, they may be used in the instrument for rear mounting. For this reason they are available with different lengths and styles of retainer shanks. These are not permanently mounted as are plate nuts; therefore, you, the instrument specialist, are required to remove and install them. This is a simple procedure, as shown in figure 5-17. They are easily dropped due to the awkward places in which they are installed. If this happens to you, you must make every effort to recover the nut. Not only do they present the hazard of shorting out electrical circuits behind the instrument panel, they could jam control cables or linkages for landing gear systems, throttles, and flight controls.

Always use the correct nut for its intended use. Match the nut to the type of bolt, steel nuts on steel bolts, aluminum nuts on aluminum bolts, etc. Make sure the size and threads are correct, and that the nut can be secured in the proper manner.

Exercises (292):

1. Name the general groups of nuts.

2. How are nuts identified?

3. State an important requirement for mating nuts.

4. Which types of nuts are required to be safety-wired?

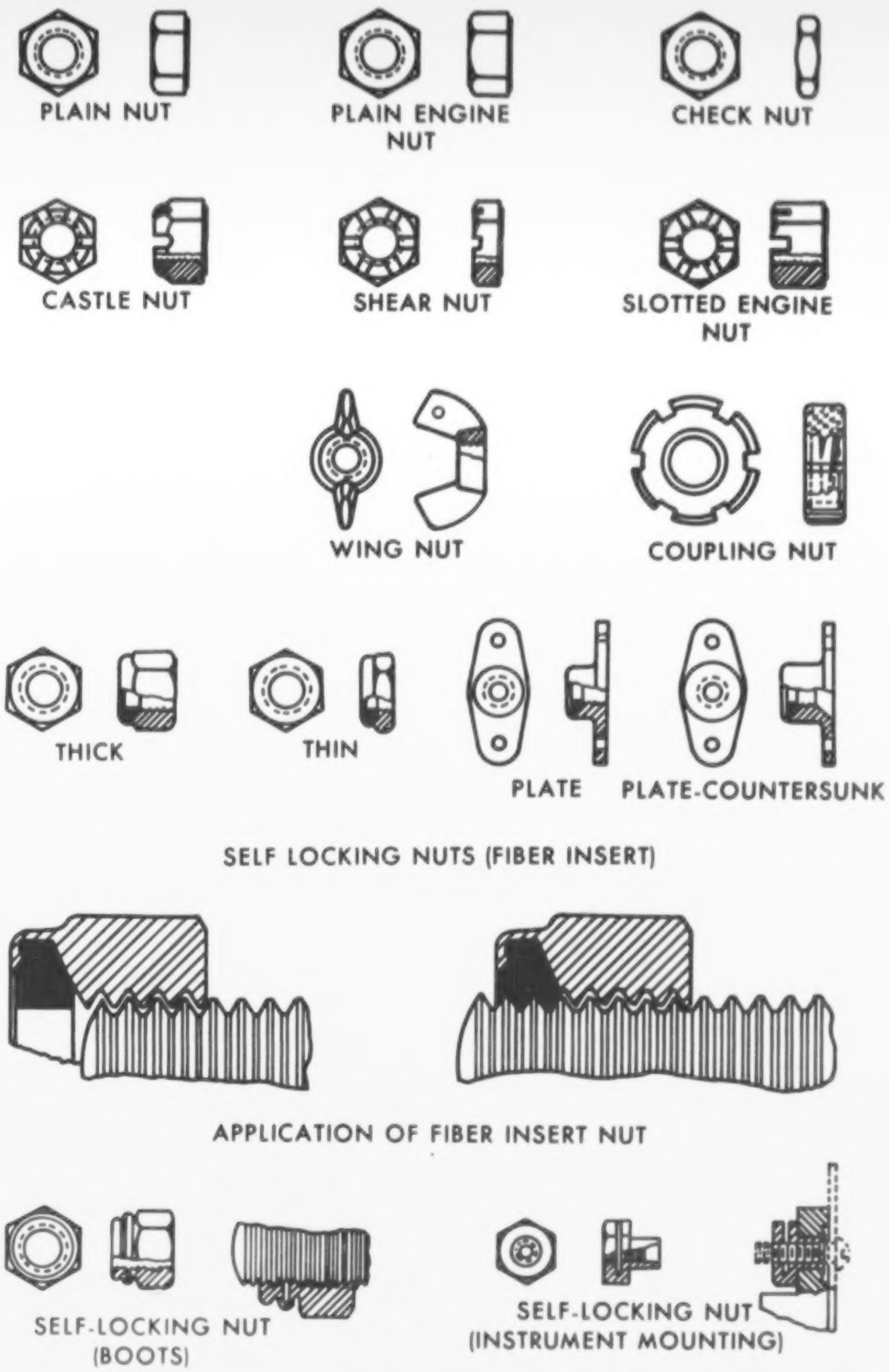

PLAIN NUT
PLAIN ENGINE NUT
CHECK NUT
CASTLE NUT
SHEAR NUT
SLOTTED ENGINE NUT
WING NUT
COUPLING NUT
THICK
THIN
PLATE
PLATE-COUNTERSUNK
SELF LOCKING NUTS (FIBER INSERT)
APPLICATION OF FIBER INSERT NUT
SELF-LOCKING NUT (BOOTS)
SELF-LOCKING NUT (INSTRUMENT MOUNTING)

Figure 5-15. Types of nuts.

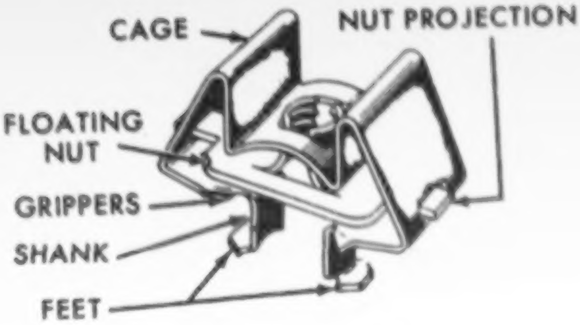


Figure 5-16. Tinnerman nut.

293. State the uses of different types of washers.

Washers. Although there are many kinds of special purpose washers, most washers used are either plain (flat) or lock. Plain washers are normally used to protect the surface of the material upon which the nut or bolt head would bear. Turning a nut against a painted surface or soft material such as aluminum would gouge or scratch the surface, thus inviting corrosion. Plain washers are also used as spacers to line up the slots of castellated nuts with the drilled cotter pin holes in bolts.

Lockwashers are used with screws and bolts whenever the self-locking or castellated type of nut is not used. The spring action of the washer provides friction to prevent loosening of the nut.

Exercises (293):

1. State the purpose of plain or flat washers.

2. Give another use of flat washers.

3. How do lock washers prevent loosening of nuts or bolts?

294. Identify and state the uses of different screws.

Screws. Much like the bolt, the screw is a common threaded fastening device. Screws may be made of steel, aluminum alloy, or brass. We will discuss the categories of screws frequently used in aircraft maintenance.

Machine screws. Machine screws are designed to be threaded into holes or nuts tapped with matching threads. They come in many different sizes and of different materials. Each different type is used for different applications. Carefully select the proper type for each job in accordance with the proper technical manual. (See fig. 5-18).

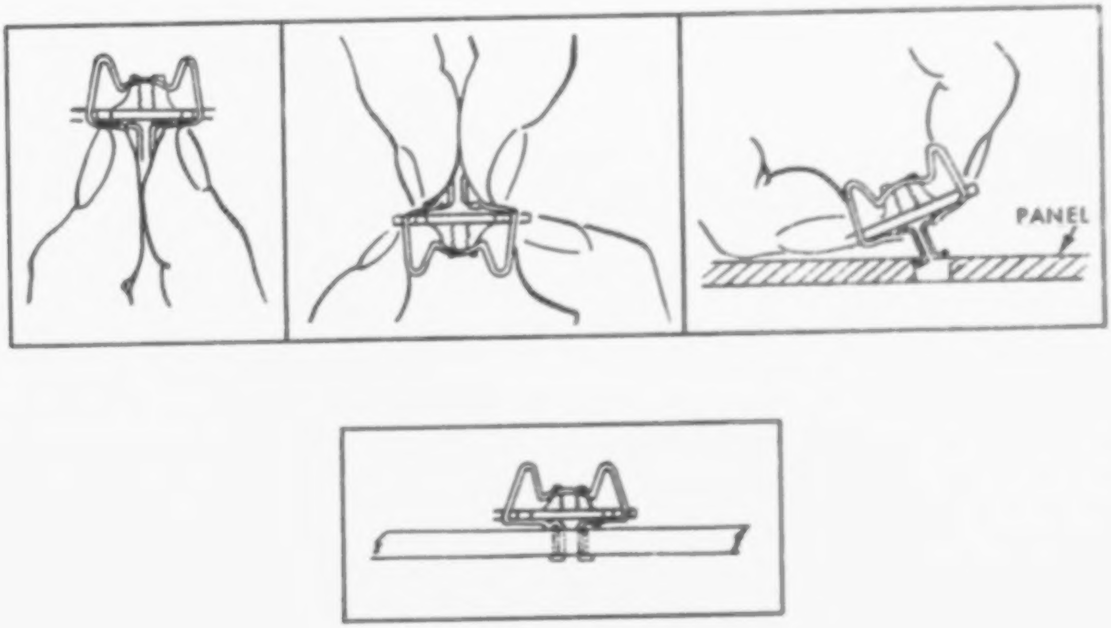


Figure 5-17. Tinnerman nut installation.

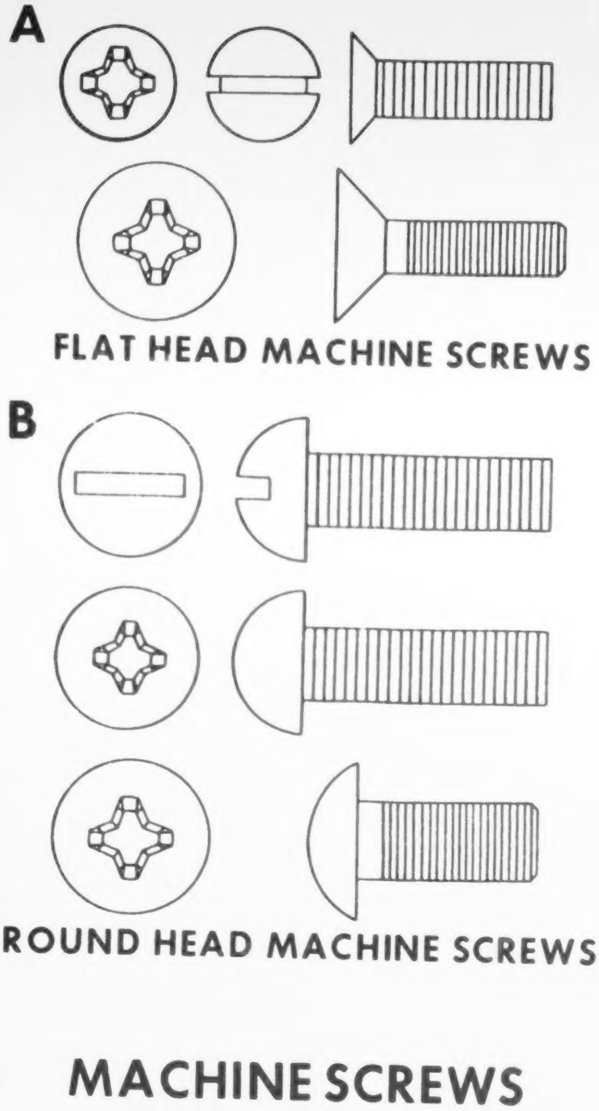


Figure 5–18. Examples of machine screws.

Sheet metal screws. Sheet metal screws are made of hardened steel so that they can tap their own threads in holes that are drilled or punched in sheet metal. Their self-threading feature is advantageous in installations that are accessible from one side only. (See fig. 5-19).

Drive screws. Drive screws also are made of hardened steel. They do not have slots for using a screwdriver but are designed to be hammered into an untapped hole slightly smaller in diameter than the screw. Spiral grooves are cut in the metal by the screw as it is driven into the hole. The resulting grooves mate very tightly with the threads of the screw. Drive screws are often used to secure such items as data plates to equipment.

Identification of screws. Screws not only are identified according to use as described above but also are identified by the shape of their heads and the screwdriver slots in the heads. Figure 5-20 shows several different types of screws you will encounter. Round head, button head, fillister head, and washer head screws are normally used where head projections are not objectionable. Fillister head screws may be drilled to accommodate safety wire. Countersunk screws, identified in figure 5-20 as Phillips head, flat head, and Reed and Prince head are used where head projections are objectionable.

Exercises (294):

1. How are machine screws intended to be used?

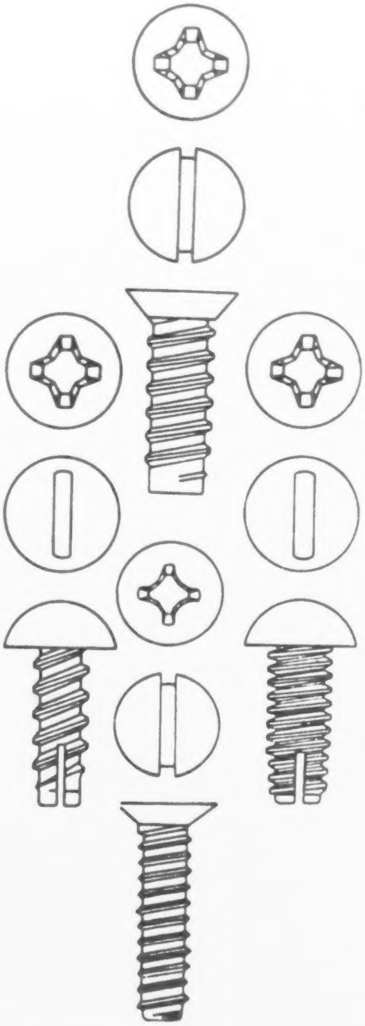


Figure 5–19. Types of sheet metal screws.

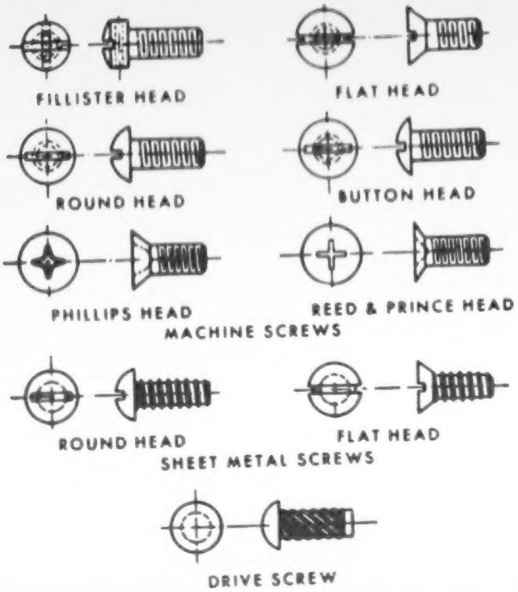


Figure 5-20. Common types of screws.

2. What are sheet metal screws made of?

3. What type of screw is frequently used to secure data plates on instruments?

4. Where are button head screws used?

5. What type of screws are used where head projections are objectionable?

295. Specify the use, sizing, and storage of different types of hoses and tubing.

Modern aircraft have hundreds of feet of fluid and airlines running throughout their wings and fuselage. The instrument specialist is responsible for inspecting and maintaining many of those carrying fuel, oil, water, and pitot and static air.

Hoses. Hoses used in instrument systems range from low-pressure rubber hose to high-pressure, steel-reinforced, synthetic rubber hose.

MIL–H–5593 Hose. This is a low-pressure hose for use as a flexible connection on low-pressure air and vacuum instrument systems. The outer surface of the hose will carry a yellow indicator stripe consisting of dots and dashes running lengthwise. Along with the indicator strip will be the symbol "LP," size number, and date of manufacture in quarter of year and year.

MIL–H–8794 hose. This is a medium pressure hose for use in hydraulic, fuel, and oil (petroleum-based products) systems. The outer surface will be identified with yellow specification numbers, size number, date of manufacture, and Federal Supply Code Number.

MIL–H–7938 hose. This is a low-pressure flame resistant hose used for fuel and oil in engine compartments. The outer surface of the hose will be identified with a broken red stripe and broken white stripe.

Aeroquip 601 and stratoflex 156 series hose. This is a medium pressure rubber hose for use in aircraft power plant (engine) and other fuel, oil, and hydraulic lines. It is widely used where flexibility, light weight, and ability to withstand high operating temperatures with maximum fire resistance are prime considerations. The hose is identified by bright braid outer cover and ID markings.

TO 42E1–1–1, Aerospace Hose Assemblies, provides more detailed information about the different hoses and their applications.

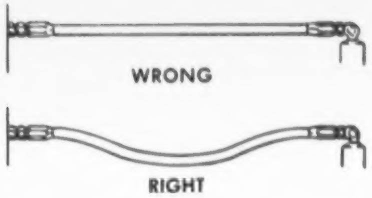
Hose size. As was implied previously under the discussion of the MIL–H–8794 hose, hose comes in several different sizes. The size is designated by a dash number (–4, –6, –8, etc.), which is stenciled on the outer covering of the hose. This dash number does not denote the inside or outside diameter of the hose; it designates the size of the tubing it is used with. For example, a – hose is used with –6 tubing. The reason for this is that the inside diameter of both the –6 hose and –6 tubing is approximately the same.

Hose storage. The storage life of rubber hose is limited. As a general rule, hose that is over 4 years old, or is showing signs of weather checking, cracks, or separation of plies, should not be used on aircraft or accessories. Hose should be stored in a straight position, but, if necessary, can be coiled in a large noose.

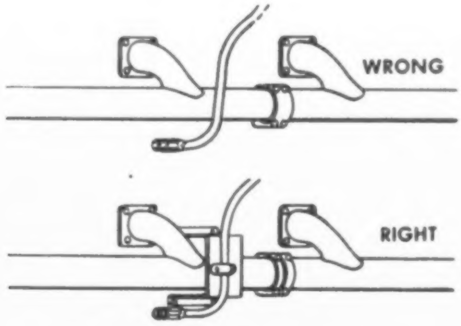
Installation of flexible hose assemblies. Flexible hose must not be twisted on installation since this reduces the life of the hose considerably and may cause the fittings to loosen as well. Twisting of the hose can be determined from the identification markings stenciled along the length of the hose. These markings should not spiral around the hose. Twisting of low pressure hose produces flat spots and collapses the hose, thus rendering it useless.

Bending any hose too sharply will reduce the service life of the hose and may even restrict the flow through the hose. Neither should a hose be stretched tight between two fittings. Some slack should be allowed to provide freedom of movement because hose contracts in length and expands in diameter when pressure is applied. Figure 5-21 gives examples of good and bad installations.

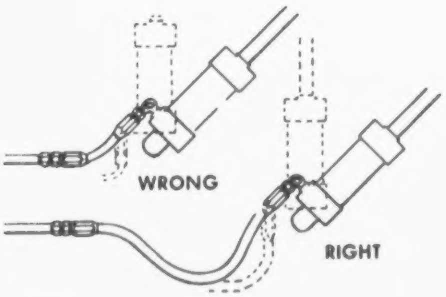
Inspection of flexible hose. All rubber hoses must be inspected for aging and deterioration. Any time you remove and replace an instrument which has a hose attached, inspect the hose for separation of the cover or braid from the inner tube or wire braid. Also look for



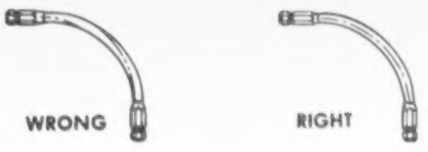
1. REMEMBER THAT THE HOSE WILL CHANGE IN LENGTH FROM +2% TO −4% WHEN PRESSURIZED. PROVIDE SLACK OR BEND IN THE HOSE TO COMPENSATE FOR ANY CHANGES IN LENGTH WHICH MIGHT OCCUR.



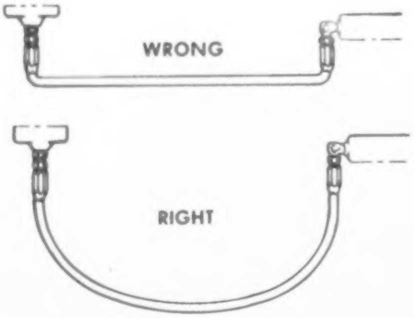
2. WHEN HOSE LINES PASS CLOSE TO A HOT EXHAUST MANIFOLD, PROTECT THE HOSE WITH FIRE PROOF BOOT OR METAL BAFFLE.



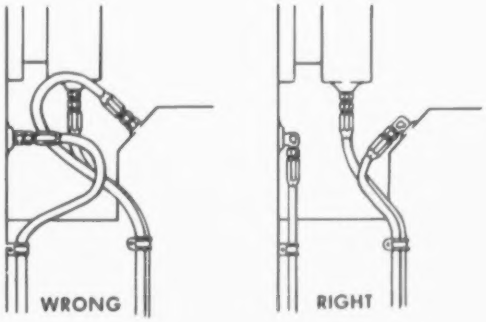
3. WHEN A HOSE ASSEMBLY IS TO BE SUBJECTED TO CONSIDERABLE FLEXING OR VIBRATION, REMEMBER THAT THE METAL HOSE FITTINGS ARE NOT PART OF THE FLEXIBLE PORTION.



4. IF HIGH OPERATING PRESSURES ARE APPLIED TO A TWISTED HOSE, THE HOSE MAY FAIL OR THE ATTACHING NUT BECOME LOOSE.



5. KEEP THE BEND RADII OF THE HOSE AS LARGE AS NECESSARY TO AVOID KINKING OF LINE AND RESTRICTION OF FLOW.



6. USE ELBOWS AND ADAPTERS TO INSURE CLEANER INSTALLATIONS FOR EASY INSPECTION AND MAINTENANCE.

Figure 5-21. Installation of hose assemblies.

cracks, hardening, lack of flexibility, evidence of abrasion, kinking, distortion, bulging, collapse, or sharp bending. Any of these conditions require the hose to be replaced.

Tubing. Tubing used in instrument systems consists of aluminum alloy and stainless steel tubing. *Aluminum alloy tubing* is used for general purpose lines carrying low and medium pressures because this tubing is light weight, easily flared, and soft enough to be formed with handtools. It should be handled with care to prevent scratches, dents, and nicks. *Stainless steel tubing* is used in high pressure systems and in areas of high temperatures and heavy vibration. The strength of the steel permits a thin wall construction, resulting in tubing almost as light weight as the aluminum alloy. TO 1-1A-8 gives more specific information including specification numbers.

Installation of tubing assemblies. Tubing does not stretch and therefore must be cut and assembled to the required length. The tubing should not have to be pulled into place with the nut, but should be properly aligned prior to tightening. When forming tubing, exercise care in bending it. Figure 5-22 shows acceptable and unacceptable tubing bends.

Inspection of tubing. Primarily, installed tubing should be inspected for damage which could have occurred since installation. This includes kinks, nicks, cuts, scratches, and other evidence of chaffing. Nicks, scratches, and similar damage produces mechanical property changes in metal tubing material that greatly reduces the ability of the tubing to withstand internal pressure and vibration.

Exercises (295):

1. What type of hose is used in instrument air and vacuum systems?

2. How is medium pressure hose for use in fuel and oil systems marked?

3. Where and for what is flame resistant hose used?

4. Which type of hose has a bright braid outer cover? Where and why is it used?

5. What does the dash number of hose designate?

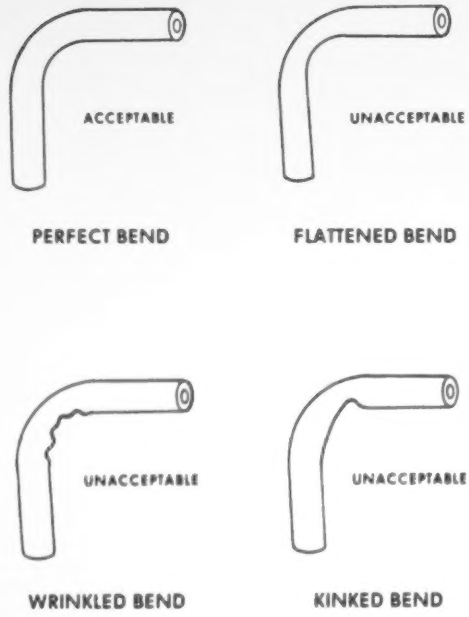


Figure 5-22. Correct and incorrect tubing bends.

6. State the general rule concerning the storage of hose.

7. Why should hose not be twisted when it is installed?

8. What should you look for when inspecting installed hose?

9. For what is aluminum alloy tubing used?

10. What type of tubing is used in high pressure systems and in areas of high temperature and heavy vibrations?

11. What should you look for when inspecting installed tubing?

296. Identify different types of fittings used in instrument systems.

Fittings. Hoses, tubing, indicators, transmitters, and other parts are connected by threaded fittings. Two major types of fittings used in instrument systems maintenance are the standard AN (Air Force–Navy) and MS (Military Standard) fittings. Both types are manufactured in many different shapes, sizes, designs, and metals.

Flared (AN) fittings. Flared (AN) fittings are available in many different shapes. Figure 5-23 shows just a few of the available designs. AN fittings have a 37° flared (beveled) face (see fig. 5-24) to which the tubing is fitted. This flared area of the fitting is the sealing surface when it is connected to tubing or hose. Tightening the B–nut too much could badly damage or completely cut off the tube flare. Further down the fitting is a seal recess. A seal (O–ring) installed in this recess forms an air tight and fluid tight seal when the fitting is screwed into an indicator or transmitter. Any imperfections on the sealing surfaces, such as nicks or scratches, usually cause leaks. Standard AN fittings are manufactured from aluminum alloy and steel. Aluminum alloy fittings are colored blue, and steel fittings are black. The material from which a fitting is made can also be identified by the part number of the fitting. For example: AN6289–4 is made of carbon steel, and AN6289D4 is made of an aluminum alloy.

Notice that the absence or inclusion of a letter following the basic part of the part number designates the material the fitting is made of. The complete part number shows

AN 6289 D 4

Size of fitting in 16th inch—4/16th inch
Material—made from aluminum
Design part number—jamnut
Prefix—Air Force—Navy

Flareless (MS) fittings. MS flareless fittings are designed primarily for high-pressure (3,000 psi) systems that are subjected to severe vibrations and fluctuating pressures. Their use is limited to fittings up to size 16 (1 inch). Above 1 inch, AN fittings are used.

Like the AN flared fittings, the MS flareless fittings come in many shapes, sizes, and designs. (See fig. 5-25). The MS flareless fittings have straight (machine) threads like the standard AN flared fitting; hence, they will mate with existing AN threads in valves, indicators, transmitters, and other equipment.

Although, the threads of MS flareless fittings will mate with the threads of standard AN fittings, the sealing surfaces will not mate. MS fittings have an internal cone seat set at a 24° angle, as shown by the broken lines in figure 5-26. Notice that there is a ledge at the base of the cone seat where the tubing bottoms as it is forced into the

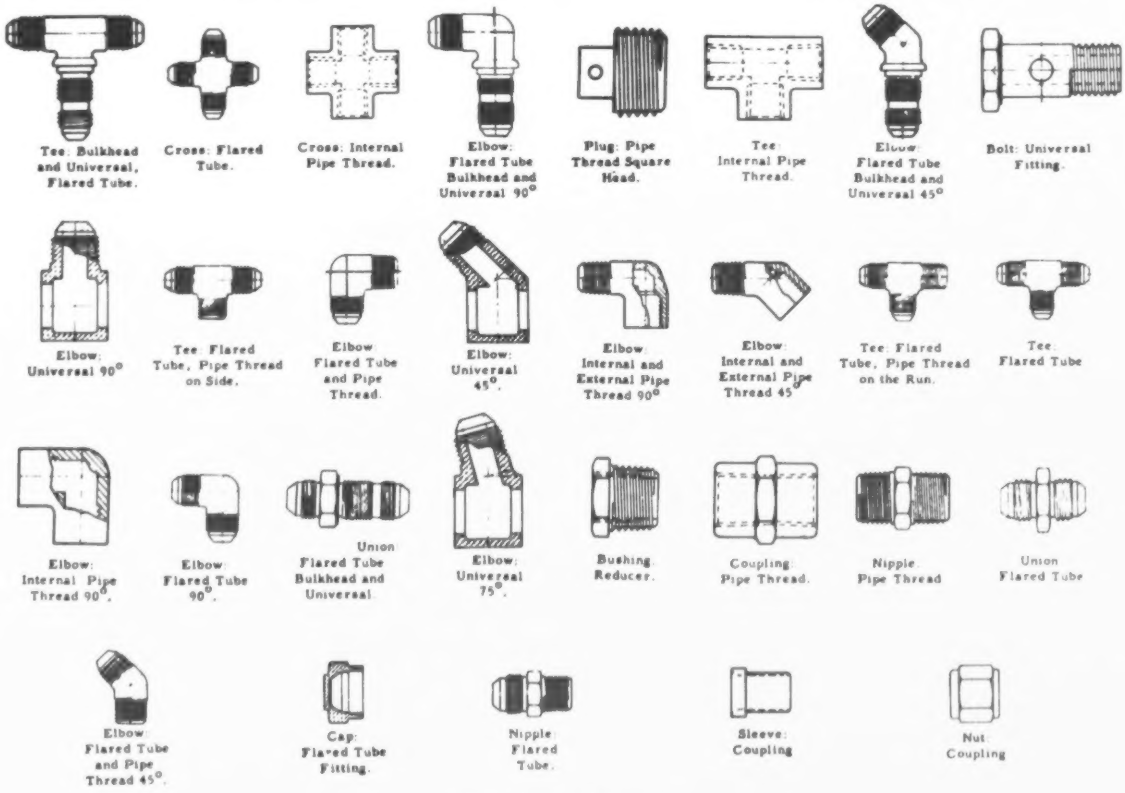

Tee: Bulkhead and Universal, Flared Tube.
Cross: Flared Tube.
Cross: Internal Pipe Thread.
Elbow: Flared Tube Bulkhead and Universal 90°
Plug: Pipe Thread Square Head.
Tee: Internal Pipe Thread.
Elbow: Flared Tube Bulkhead and Universal 45°
Bolt: Universal Fitting.
Elbow: Universal 90°
Tee: Flared Tube, Pipe Thread on Side.
Elbow: Flared Tube and Pipe Thread.
Elbow: Universal 45°.
Elbow: Internal and External Pipe Thread 90°
Elbow: Internal and External Pipe Thread 45°
Tee: Flared Tube, Pipe Thread on the Run.
Tee: Flared Tube
Elbow: Internal Pipe Thread 90°.
Elbow: Flared Tube 90°.
Union: Flared Tube Bulkhead and Universal.
Elbow: Universal 75°.
Bushing. Reducer.
Coupling: Pipe Thread.
Nipple. Pipe Thread
Union Flared Tube
Elbow: Flared Tube and Pipe Thread 45°.
Cap: Flared Tube Fitting.
Nipple: Flared Tube.
Sleeve: Coupling
Nut: Coupling

Figure 5–23. AN fittings.

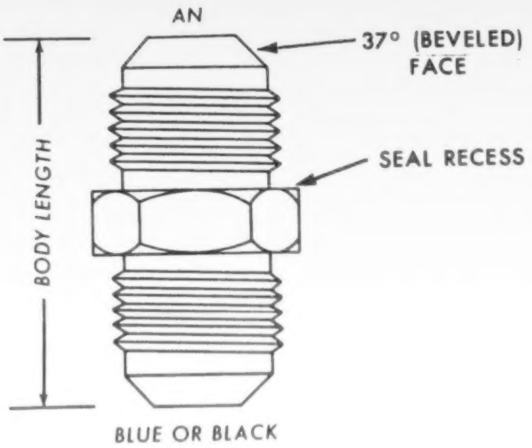

AN
37° (BEVELED) FACE
SEAL RECESS
BODY LENGTH
BLUE OR BLACK

Figure 5–24. AN union.

fitting. This ledge, labeled in figure 5-26 as a reverse angle tubing seat, is set at an angle to prevent excessive inward collapse of thin-walled tubing when the fitting is tightened.

MS flareless fittings made of aluminum are colored yellow, green, or brown. Steel MS flareless fittings are silver-colored (natural cadmium-plated). The method of making up part numbers for MS flareless fittings is the same as for AN flared fittings. A number is added to the basic part number to indicate the outside diameter of the tubing it is used with. A letter placed between the basic part number and size number denotes the material it is made from.

Exercises (296):

1. What is the purpose of the recess on an AN fitting?

2. What color is an AN aluminum fitting?

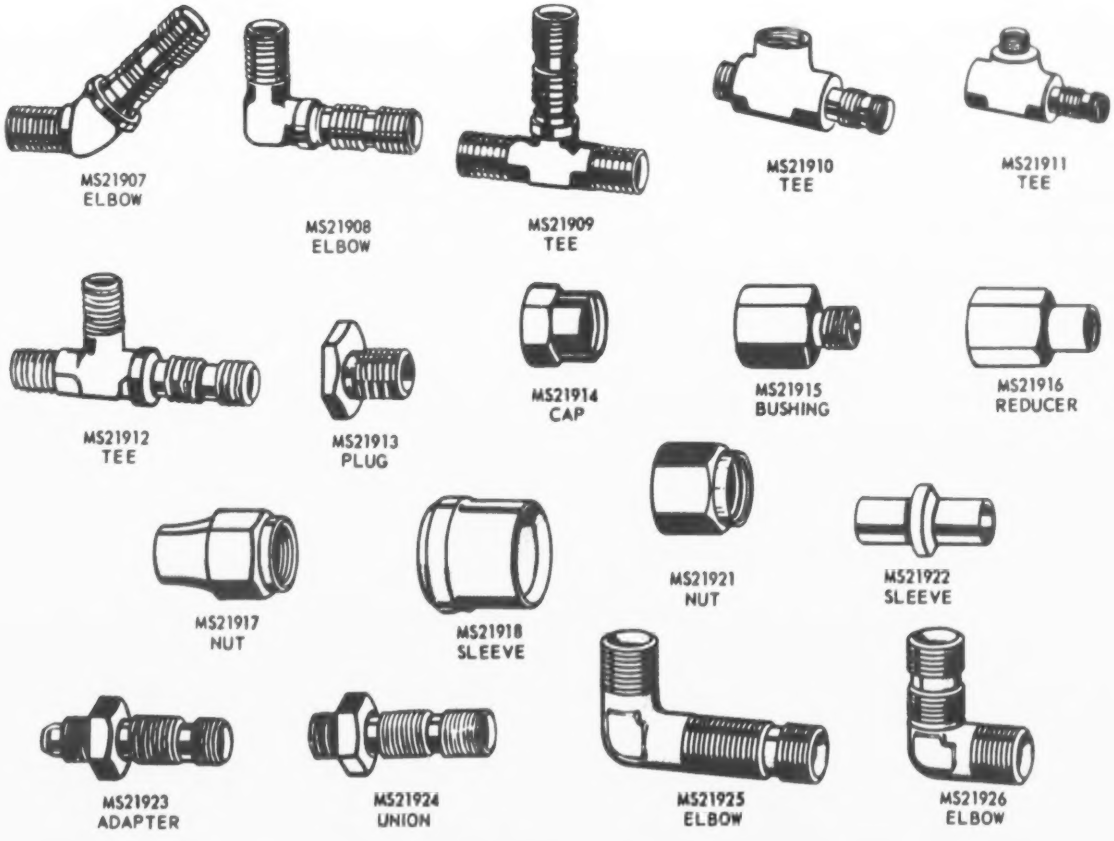

MS21907
ELBOW
MS21908
ELBOW
MS21909
TEE
MS21910
TEE
MS21911
TEE
MS21912
TEE
MS21913
PLUG
MS21914
CAP
MS21915
BUSHING
MS21916
REDUCER
MS21917
NUT
MS21918
SLEEVE
MS21921
NUT
MS21922
SLEEVE
MS21923
ADAPTER
MS21924
UNION
MS21925
ELBOW
MS21926
ELBOW

Figure 5–25. MS fittings.

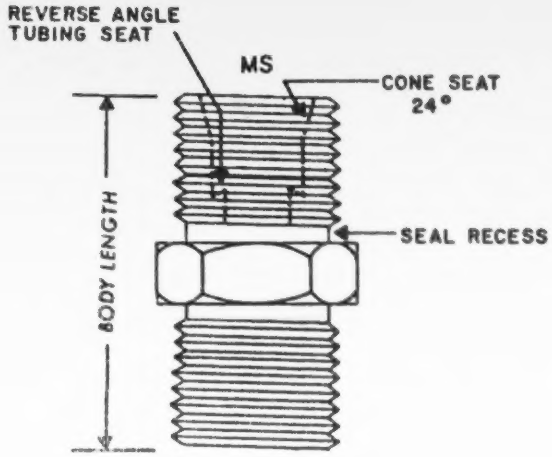


Figure 5–26. MS union.

3. What information is contained in the part number of a fitting?

4. MS fittings were primarily designed for what?

5. What kind of threads are used on AN and MS fittings?

6. Of the two types of fittings discussed, which type has an external beveled seat?

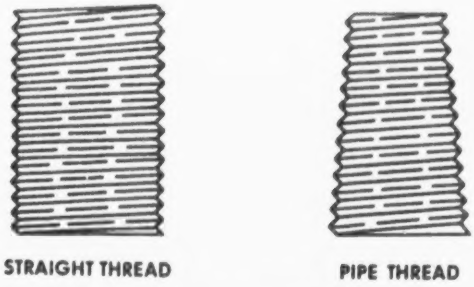


Figure 5–27. Pipe and straight threads.

297. State proper fitting installation practices and, from problems given, specify probable violations of those procedures.

Fitting Installation. A fitting, depending upon its type and use, will have either standard machine threads or pipe threads. Figure 5-27 is provided to illustrate the differences.

a. Pipe threads. Pipe threads, such as used in ordinary household plumbing, are tapered as shown in figure 5-27. When two pipe fittings are joined, a male into a female, their threads form a seal. They mate so tightly that an antiseize compound should be used to prevent seizing and leakage. However, teflon tape or other solid types of antiseize material must not be used on instrument systems because the material may get on the end of the fitting where it may enter and contaminate the system. When installing pipe thread fittings, be careful not to tighten them too much; this could damage the threads or crack the part in which the fitting is being installed.

b. Machine threads. Machine threads are not tapered. The threads are straight as shown in figure 5-27, very much like the threads used on machine screws, nuts, and bolts. This type of thread is used to draw and hold connections together rather than to form a seal. Some other method must be used to make the connection fluid tight or air tight. Let's look at how common fittings are sealed.

c. Adapter fitting. Figure 5-28 shows an MS to AN adapter. In order to install this fitting into the component receptacles (boss), the proper seal is selected, lubricated, and installed in position as shown. Be careful not to damage the seal while forcing it over the fittings threads. The fitting is then screwed into the boss of the component unit it bottoms, then torqued to TO specification. Without a seal, this type of connection would leak.

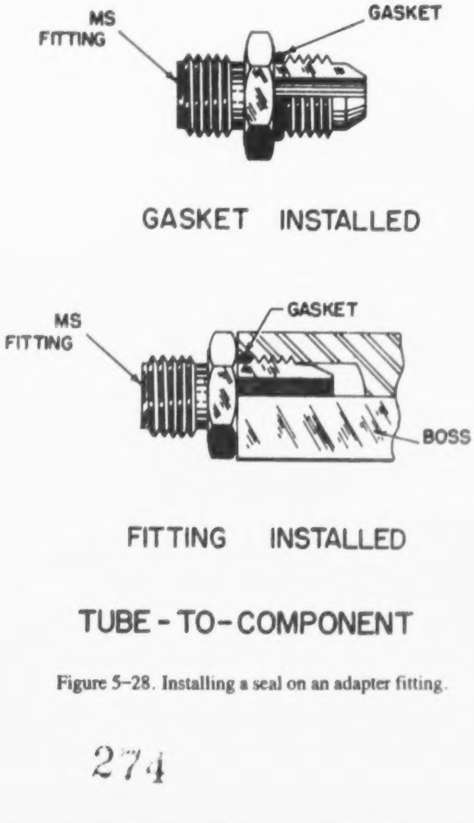


Figure 5–28. Installing a seal on an adapter fitting.

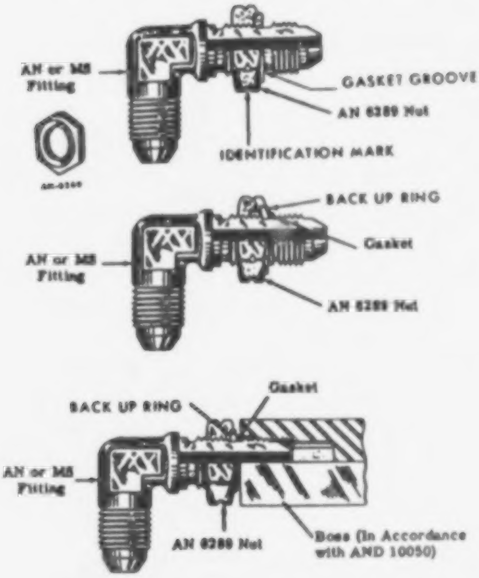


Figure 5-29. Installation of a universal fitting.

d. Universal fittings. Refer to figure 5-29. The first step n installation procedure is to install the jamnut onto the hreads of the fitting. Be sure to use the proper jamnut. If a ackup ring is going to be used, you must use a jamnut with recess (AN6289). The recess can be identified by an ndentation on the outer circumference of the nut.

Work the backup ring (MS9058) in the recess in the nut, hen lubricate with system fluid and install the gasket MS28778). Turn the nut down until the gasket is pushed irmly against the lower threaded section of the fitting. This is shown in the center illustration in figure 5-29. Screw the fitting into the boss by hand, and at the same time keep the nut turning with the fitting until the gasket contacts the boss. This point can be determined by a sudden increase in torque (see bottom illustration of fig. 5-29). With the fitting in this position, put a wrench on the nut to prevent its turning. Then turn the fitting in 1 1/2 turns. Now, position the fitting (if it is an elbow or tee) by turning it in not more than one additional turn. Finally, hold the fitting and turn the nut down tightly against the boss to the required torque. There must be no extrusion of the backup ring or seal. In many cases, leaks have developed because of the improper installation of universal fittings. One of the reasons a universal fitting might leak is that the jamnut is not positioned properly. This causes the seal to ride up on the threads, which cuts the seal. Another reason is that the jamnut might become stripped, which is caused by insufficient thread grip when the jamnut is torqued to the proper value. Instances cited above are reasons why it is so important to take the time to properly install a universal fitting.

As stated earlier, aluminum fittings should only be used with aluminum tubing and mated with other aluminum fitting. Mating steel with aluminum fittings frequently results in stripped threads. More important though, mating of dissimilar metals accelerates corrosion, which causes seized connections and results in leaks in the system. Heat and exhaust gasses accelerate this corrosion even more.

Exercises (297):

1. State when antiseize tape may be used in instrument systems.

2. If you had trouble removing a pipe thread fitting, what could be the problem?

3. If, while tightening the jamnut on a universal fitting, you notice that it keeps turning and doesn't seem to bottom, what is the probable cause of the problem?

4. You are performing a pressure check after installing a rubber seal on a fitting. You notice that the fitting is leaking even though you installed a new seal. What is probably wrong?

5-3. Handtools

Although we have completed the chapter on occupational safety and health, safety will continue to be a predominant subject throughout this course. We will start this section with some general safety rules about hand tools.

298. State the basic rules in the use of handtools.

Basic Rule for Use of Handtools. What is so important about handtools? Statistics show that handtools contribute to many of the so-called accidental injuries to mechanics. Tools may be a contributing factor, but tools do not cause accidents. Personal injury and damage to equipment occur from the improper use of tools. Every tool is designed for one or more specific purposes, and using the correct tool will let you do any job faster, easier, and much more safely than you could using a substitute or make shift tool.

Your efficiency on the job and the quality of your work depend upon your knowledge of handtools and the skill you develop in their use. Through OJT and practice, you should learn how to properly select, care for, and use your tools. The material you are studying in this section comes primarily from AFR 127-101, *Ground Accident Prevention Handbook*, and TO 32-1-101, Use of Handtools.

Throughout this section, specific safety hazards are pointed out for each tool; however, there are several basic rules listed below that apply regardless of the tool being used.

a. Select the right tool for the job. Do not substitute one tool for doing the job of another. Using a file as a pry bar, a wrench for a hammer, etc., is asking for trouble, and trouble won't be long in coming. Files are made of a hardened metal so as to cut away or smooth a surface; therefore, they are very brittle and break easy.

b. Keep your tools clean. Any oil or grease should be wiped off immediately after use. Oil helps prevent rust, but it also makes for a messy toolbox, dirty fatigues, and slippery hands. Slippery hands, in turn, can often result in bruised knuckles or lost tempers.

c. Keep tools in a safe place. Never carry tools in pockets or leave them lying around. It is a fact that many fatigues are torn and airmen have been accidentally punctured because they violated this rule.

d. Wear safety glasses or goggles when soldering, using power tools, or doing anything else which creates the hazard of flying particles.

e. Use only authorized maintenance techniques and materials.

f. Keep your work area neat, and clean it thoroughly when the job is completed.

g. Keep your tools in your toolbox so that they will be available when you need them.

h. Speaking of tool boxes, they are for storing tools only. You should not use them for seats or stands.

i. Know the location of all safety equipment, and be familiar with its use and operation.

j. Report all accidents, no matter how slight. Accident reports have been very helpful in improving the design of our tools and in developing better and safer maintenance techniques.

k. The best and last rule is "develop safe work habits and use common sense."

Exercises (298):

1. Why should you select the proper tool for each job?

2. Oiling tools helps prevent rust, but what hazard does it present?

3. When the job is finished, what is another thing you should do? Why?

4. Why should all accidents, even insignificant ones, be reported?

299. Differentiate among the uses of specified screwdrivers.

Screwdrivers. The screwdriver is one of the most frequently used and abused tools. It is designed for one purpose only—to tighten or loosen screws. To accomplish this purpose without hurting yourself or damaging the screw or adjacent equipment, you need to select the proper type and size for the job to be done.

Common screwdriver. Common screwdrivers are available in different lengths and tip widths in two basic tip styles, which are shown in figure 5-30. The length is measured from the end of the blade to the handle. The larger of the common screwdrivers usually has a thick, square shank so that a wrench can be used to turn it. However, a wrench should never be used on screwdrivers with thin round shanks. A wrench may be used on the flat portion of the tip, but care must be taken to prevent damage to the screwdriver tip or to the head of the screw. The width and thickness of the blade of the screwdriver depends on the size of the screw head. Figure 5-30,C shows an example of both an incorrect and a proper fit. Figure 5-30,A shows the two types of screwdriver tips. The straight tip (sometimes called a cabinet screwdriver) is used for recessed screws and for use in places which are inaccessible with the flare tip screwdriver.

Screw starter. Occasionally, a screw will have to be installed or removed in an area where it is difficult to reach the screw. When this occurs, a screw starter should be used. This tool has a spring-loaded, expandable point that can be inserted into the screw slot and expanded to a tight fit, enabling you to insert the screw into the hole. The screw starter should not be used to drive a screw in tight or to loosen a screw because the spring-loaded point is weak and will snap or slip when excessive torque is applied.

Crosspoint screwdriver. The two types of crosspoint screwdrivers are the Phillips and the Reed and Prince, figure 5-30,B. At first glance the two tips of the screwdrivers appear to be identical. But on close examination, you can see that the Phillips tip is blunt and that the Reed and Prince tip is pointed. The size of the screwdriver is determined by the length of the shank and the size of its tip. They come in tip sizes of #1, #2, and #3. The #1 tip is the smallest.

Offest screwdriver. The offset screwdriver is used, primarily, when the screw head is almost inaccessible. It is difficult to handle because the blade has a tendency to slip out of the screw slot if care is not exercised. The two blades of this screwdriver are made at right angles to each other in order that a screw can be turned a quarter turn at a time by using the opposite ends of the screwdriver alternately. This screwdriver is available in three different types of points—common, Phillips, and Reed and Prince.

Ratchet screwdriver. Ratchet screwdrivers are similar to offset screwdrivers in that they are used when the screw head is located in an area where a standard screwdriver will not fit. The ratchet screwdriver, however, is designed so that once the blade is inserted into the screw slot, the screw can be turned completely out or in by utilizing the ratchet action without removing and reinserting the blade for each turn of the screw. Ratchet direction of this type screwdriver

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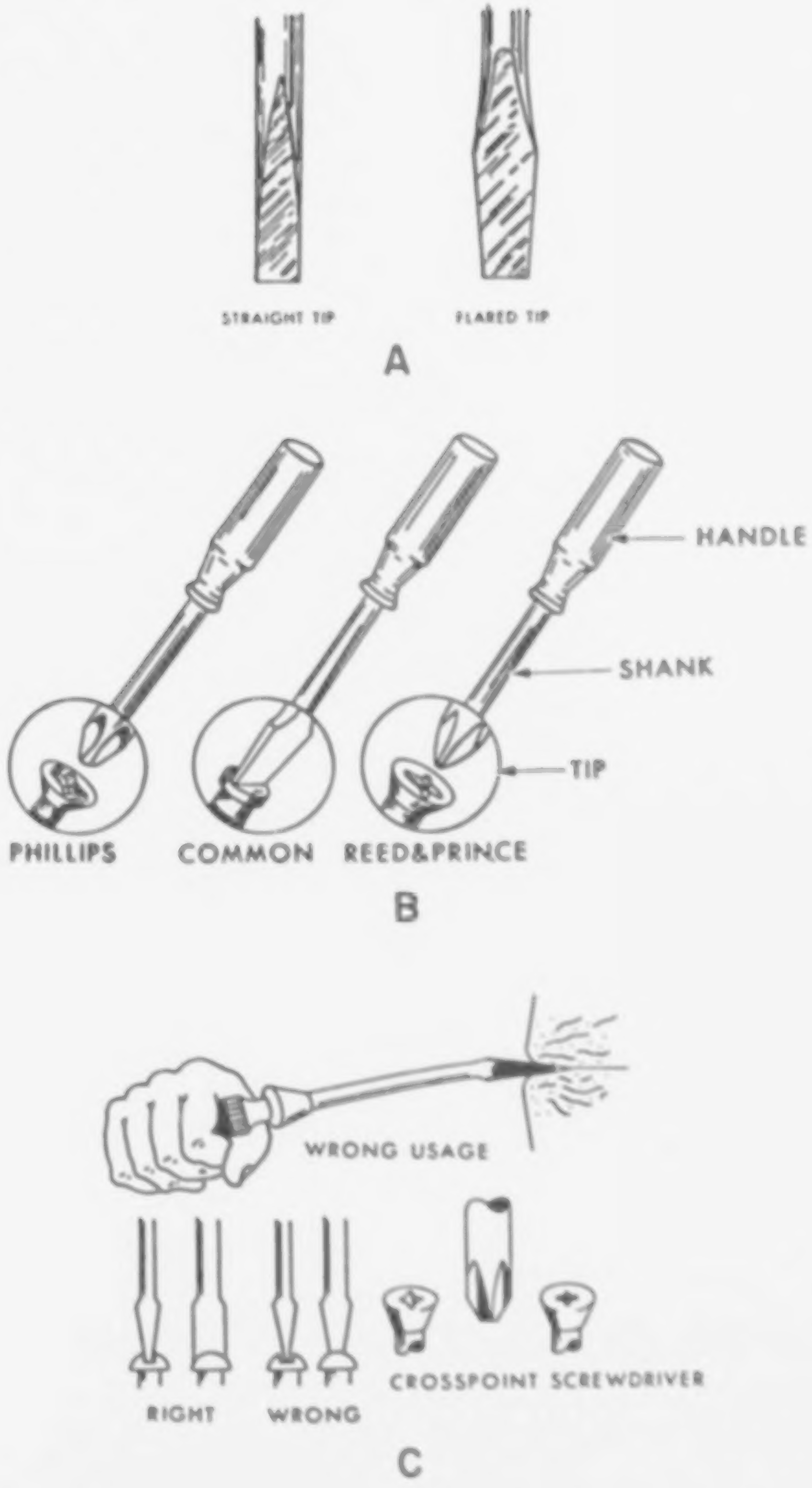
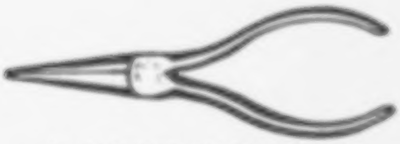
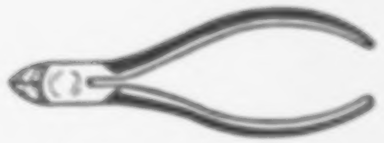

STRAIGHT TIP
FLARED TIP
A
HANDLE
SHANK
TIP
PHILLIPS
COMMON
REED&PRINCE
B
WRONG USAGE
CROSSPOINT SCREWDRIVER
RIGHT
WRONG
C

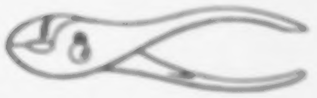
Figure 5-30. Types and correct fit of screwdrivers.



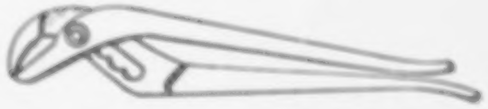
A. HALF-ROUND NOSE PLIERS



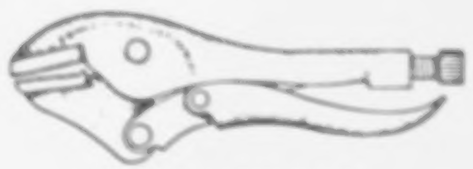
B. DIAGONAL CUTTING PLIERS



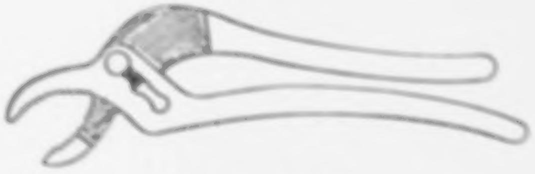
C. COMMON SLIP-JOINT PLIERS



D. WATER PUMP PLIERS



E. VISE-GRIP PLIERS



F. CONDUIT PLIERS

Figure 5-31. Types of pliers.

is controlled by a small lever on the handle of the screwdriver. This screwdriver is also available in three different types—common, Phillips, and Reed and Prince.

You have probably seen some of the common abuses of screwdrivers. Often screwdrivers are used for everything from pry bars to chisels. These practices certainly are not becoming to the person who wants to be considered a technician or a specialist. In a class alone, however, is the person who uses a screwdriver to test for voltage in an electrical circuit. Such misuse is apt to damage the blade of the screwdriver; however, there is more likelihood of serious damage to the electrical equipment concerned and serious injury to the person who would have such utter disregard for his or her own personal safety. Another misuse of the screwdriver that you might observe is that of holding the work in your hand. If the blade should slip out of the slot in the screwhead, you are likely to drive the screwdriver tip into your hand. Don't forget that a screwdriver, like other tools, finally reaches a point in wear that makes its further use impractical. At that point you should turn it in for salvage and replacement.

Exercises (299):

1. How does a Phillips screwdriver differ from the standard screwdriver?

2. State the main advantage of a ratchet screwdriver.

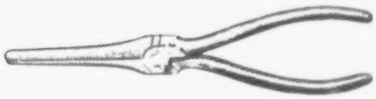
3. What type of screwdriver should you use to work in places that are inaccessible with a standard screwdriver?

300. Name the proper pliers to use for specific purposes and state some of the misuses of screwdrivers.

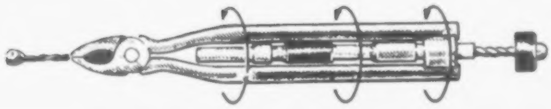
Pliers. Pliers are used for gripping, bending, forming, or holding work, and in some cases for cutting. There are many types and sizes of pliers, and each type is designed for a specific purpose. They should not be used as hammers; nor should they be used to remove and insert nuts and bolts.

Half-round nose and needle-nose pliers. These pliers are used for general electrical work when work space is limited and the parts are small in size. Half-round-nose pliers, sometimes called long-nose pliers (fig. 5-31,A), have a pair of long, tapering jaws, half-round on the outside and flat on the inside. They may or may not have side cutters behind the gripping surface of the jaws. Needle-nose pliers (not shown) can also be used to form small loops in a piece of wire prior to connecting the wire to a terminal pin. The jaws of these pliers are weak and should not be used for heavy gripping. Heavy gripping could result in breaking the jaws or bending them so that they do not close firmly on small objects.

Diagonal pliers. Diagonal pliers (fig. 5-31,B), sometimes called dikes, are used to cut small-sized wire and component leads. The principal advantage of diagonal pliers over side-cutting pliers is the fact that, because of their design, they can cut off a wire closer to its point of attachment. These pliers can be damaged easily and should



DUCK BILL



WIRE TWISTER

Figure 5–32. Duckbill and safety wire pliers.

not be used to cut nails or similar objects. The wire to be cut should be placed as close to the pivot of the cutting jaws as possible and not at the points. This reduces the tendency to spring the jaws apart. Once the jaws are spread, it is difficult to cut small-sized wire. When you are using diagonal cutters, point the inside of the cutting jaws away from your face to prevent injury from flying clippings.

Retaining ring pliers. Retaining ring pliers (not shown) are used to insert and remove retaining rings. By inserting the pointed jaws of these pliers into the holes of the retaining ring, you can expand the ring, allowing easy removal or installation. The adjustment screw located on the jaws is used to limit the amount of expansion, preventing excessive spreading of the retaining ring. These pliers come in various sizes, and care should be exercised to prevent damage to the pointed jaws.

Common pliers. Common pliers, also called combination slip-joint pliers (fig. 5-31,C), have serrated (grooved) jaws. The screw or pivot with which the jaws are fastened together may be moved in a small slot so that the jaws will open to two widths. To spread the jaws of slip-joint pliers in order to change the size of the jaw opening, spread the handles as far apart as possible. Push the slip joint or pivot to the end of the slot that gives the desired size jaw opening, and close the handles to hold it there. The pivot will not slide in the slot unless the handles are wide open. To use these pliers, place the plier jaws on the work object so that the serrations will keep the work from slipping. Close the jaws by squeezing the handles tightly.

Water pump pliers. Water pump pliers (fig. 5-31,D) are also known as arc pliers, channel locks, multi-slip-joint pliers, or tongue and groove pliers. The jaws of the pliers remain at the same angle to each other no matter how wide they are spread apart. One variety of these pliers has a slip joint similar to the combination slipjoint pliers in figure 5-31,C, and the other variety uses a tongue and groove assembly to adjust for the different widths. These pliers should not be used on bolt heads or nuts.

Duckbill pliers. Duckbill pliers, as shown in figure 5-32, have long wide jaws and slender handles. Duckbills are used in confined areas where the fingers cannot be used. The jaw faces of the pliers are scored to aid in holding an item securely. Duckbills are suitable for twisting the safety wire used in securing bolts, nuts, and screws if wire-twisting pliers are not available or cannot be used.

Vise-grip pliers. Vise-grip pliers (fig. 5-31,E) are heavy-duty pliers that can be used when ample work space is available. The vise-grip pliers are designed with a locking feature that permits the user to lock the pliers on the work. The jaws of these pliers are adjustable to the minimum distance between the jaws when closed and locked. A major advantage of vise grip pliers is that, once they are locked into position, they leave both hands free to work with.

Conduit pliers. Conduit pliers (fig. 5-31,F) are also called cannon plug or connector pliers. They are similar to water pump pliers with the exception that the jaws are curved. The conduit pliers are used to loosen or tighten electrical connectors only. Some types have the jaws lined with plastic to prevent the pliers from scoring the connector.

Wire-twister pliers. Wire twisters (safety wire pliers) are three-way pliers which can hold, twist, and cut. (see fig. 5-32). They are designed to reduce the time used in twisting safety wire. To insure proper operation of the wire twisters, lubricate the spiral of the twister occasionally.

Exercises (300):

1. Name the proper pliers to use for the following maintenance actions:
    a. Forming small loops in a piece of wire.

    b. Holding your work, leaving both hands free.

    c. Cutting a wire close to its point of attachment.

2. State a misuse of the following pliers:
    a. Needle nose pliers.

    b. Retaining ring pliers.

    c. Arc pliers.

d. Conduit pliers.

301. State the proper wrenches to use for specific purposes and some precautions to take when using wrenches.

Wrenches. Fundamentally, the wrench is a tool used to apply a turning force on bolt heads, nuts, and studs. The majority of nuts are six sided and are called hex nuts, and most wrenches are designed to fit this type of nut. The size of the wrench to use is determined by the size of the jaw opening and the width of the nut. When selecting a wrench, be sure that it fits snugly on the nut, since improperly fitted wrenches (fig. 5-33,A) can cause the corners of the nut to become rounded. For safety, pull on wrenches. If they must be pushed, do so with an open palm. The reason for this is that, if your hand or the wrench slips, you are less likely to end up with skinned and bruised knuckles.

Open-end wrenches. Open-end wrenches are nonadjustable and open on either or both ends of the wrench (fig. 5-34,A). They range in size from 3/16 inch to 1 1/4 inch. On the wrenches that utilize both ends, one may be the next size larger than the other end; i.e., 5/16 inch—11/32 inch, 3/8 inch—7/16 inch. The wrench size will be marked on the handle nearest the end to which it corresponds. On others, both ends will be the same size but at different angles.

Wrenches with small openings will have shorter handles than those with large openings. This adjusts the leverage of the wrench to the nut and helps prevent damage to the wrench and the work.

The open ends of these wrenches will normally be at a 15° angle with respect to the handle; however, this angle can vary between 0° and 90°. The wrench opening is placed at an angle to facilitate working in close quarters. The handles of these wrenches are often curved or offset to facilitate the removal or insertion of nuts and bolts in recessed or out-of-the-way locations.

Box wrenches. A wrench on which the ends are closed is called a box wrench (fig. 5-34,B). The box ends of these wrenches have 6 or 12 notches in the box inclosure instead of flat surfaces like the open-end wrench. These notches make it possible to fit this wrench onto hex nuts, which are positioned at angles that an open wrench cannot fit. They can be used with a minimum swing of only 25°.

The box wrench should be used in place of the open-end wrench to break loose a difficult nut or bolt because, being closed, the jaws will not spread and there is less chance that it will slip off the nut. Once the nut is loose, the open-end wrench will be the best to use, unless there is room to swing the box wrench in a circle. If the working space is limited, the box wrench would have to be lifted off the nut and replaced, which can be difficult to do in some locations.

Cutaway box-end wrench. Another version of the box-end wrench is the cutaway box-end wrench, also known as a tube wrench, shown in figure 5-35. This wrench is designed for tightening plumbing connections. The cutaway enables the box to be slipped over the tubing and then positioned on the nut of the connection. This type of wrench has an advantage over an open-end wrench when you are tightening tube connections because there is little chance of the cutaway wrench slipping off the nut.

Adjustable wrenches. Open-end wrenches that have an adjustable jaw are called adjustable wrenches (fig. 5-34,C). Adjustable wrenches are most commonly referred to as crescent wrenches. One jaw of this wrench is fixed but the other is adjustable by use of a screw adjustment. This wrench, because it is adjustable, can fit nuts, bolts, and studs of various sizes; however, the screw adjustment is not strong, and the wrench should not be used for heavy work. This wrench also has the disadvantage of tending to round off the corners of hex nuts unless its jaws are closely adjusted to fit the nut.

When using this type of wrench, place the strain on the fixed jaw, (see fig. 5-33b), not on the movable jaw, to avoid spreading the jaws if too great a force is applied. The correct way is shown by the arrow in figure 5-34,C.

Socket wrenches. Socket wrenches (fig. 5-34,E) come with socket heads of various sizes, standard or deep well, and three different size drives. The heads of socket wrenches are available in the same sizes as those of both open-end and box wrenches. The socket wrench shown in figure 5-34,E is a 12-point socket. Six-point sockets are also available and have the advantage of being less likely to slip than the 12-point socket. Deepwell sockets are longer than standard sockets and have the advantage of being able to remove nuts that would be inaccessible to the standard socket. The length of the bolt protruding through the nut would make it impossible to remove the nut with a standard socket. Sockets are available in three different drives: 1/4-inch, 3/8-inch, and 1/2-inch.

The socket handles and accessories (fig. 5-34,F) are available in all three sizes of drives. These handles and accessories can be assembled in combinations that will do almost any job quickly and easily. To use the socket wrench, select the socket head that fits the nut, place the socket head on the handle, and then place it over the nut. The socket head is held on the handle lug by a small friction catch that engages when the socket head and handle are forced together.

Spin-tite wrench. The spin-tite (nut driver) wrench (fig. 5-34,D) resembles a screwdriver handle with a socket on the shank. Some types have a hollow shank as a deep-well socket. These wrenches, available in various sizes, are used to remove and replace small nuts. Some sets come with a large handle that can be placed over the small handle of the wrench and thus increase the amount of torque.

Spanner wrenches. Spanner wrenches are special wrenches for special jobs. There are a number of types, some of which are shown in figure 5-36. The hook spanner is for a round nut that has a series of notches cut in the outer edge. The hook or lug is placed in one of the notches with the handle pointing toward the direction in which the nut is to be turned. Some hook spanner wrenches are adjustable and will fit nuts of various diameters. U-shaped hook spanners have two lugs on the face of the wrench to fit notches cut in the face of the nut or screwplug. End spanners resemble a socket wrench but have a series of lugs

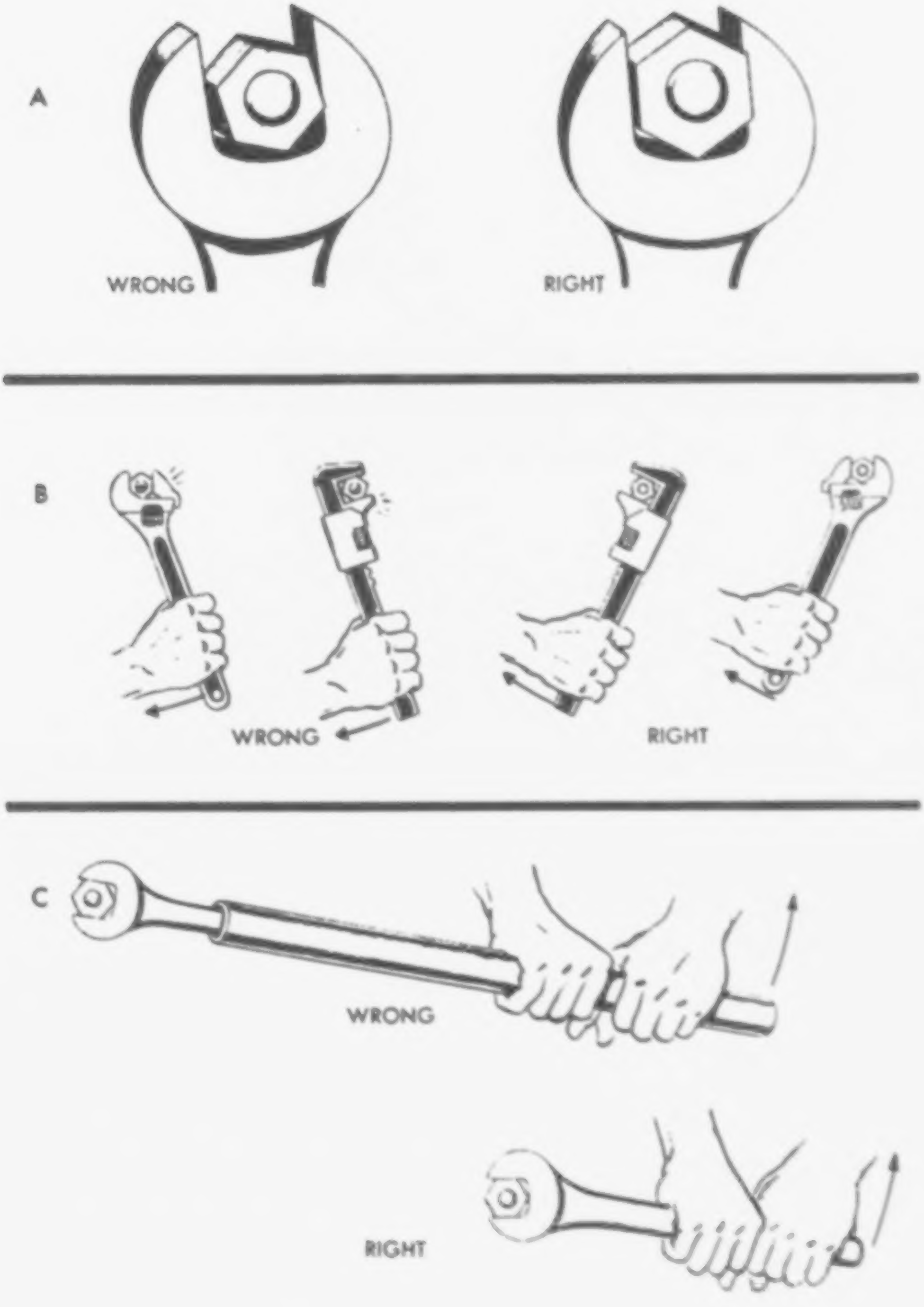

A
WRONG
RIGHT
B
WRONG
RIGHT
C
WRONG
RIGHT

Figure 5–33. Correct and incorrect use of wrenches.

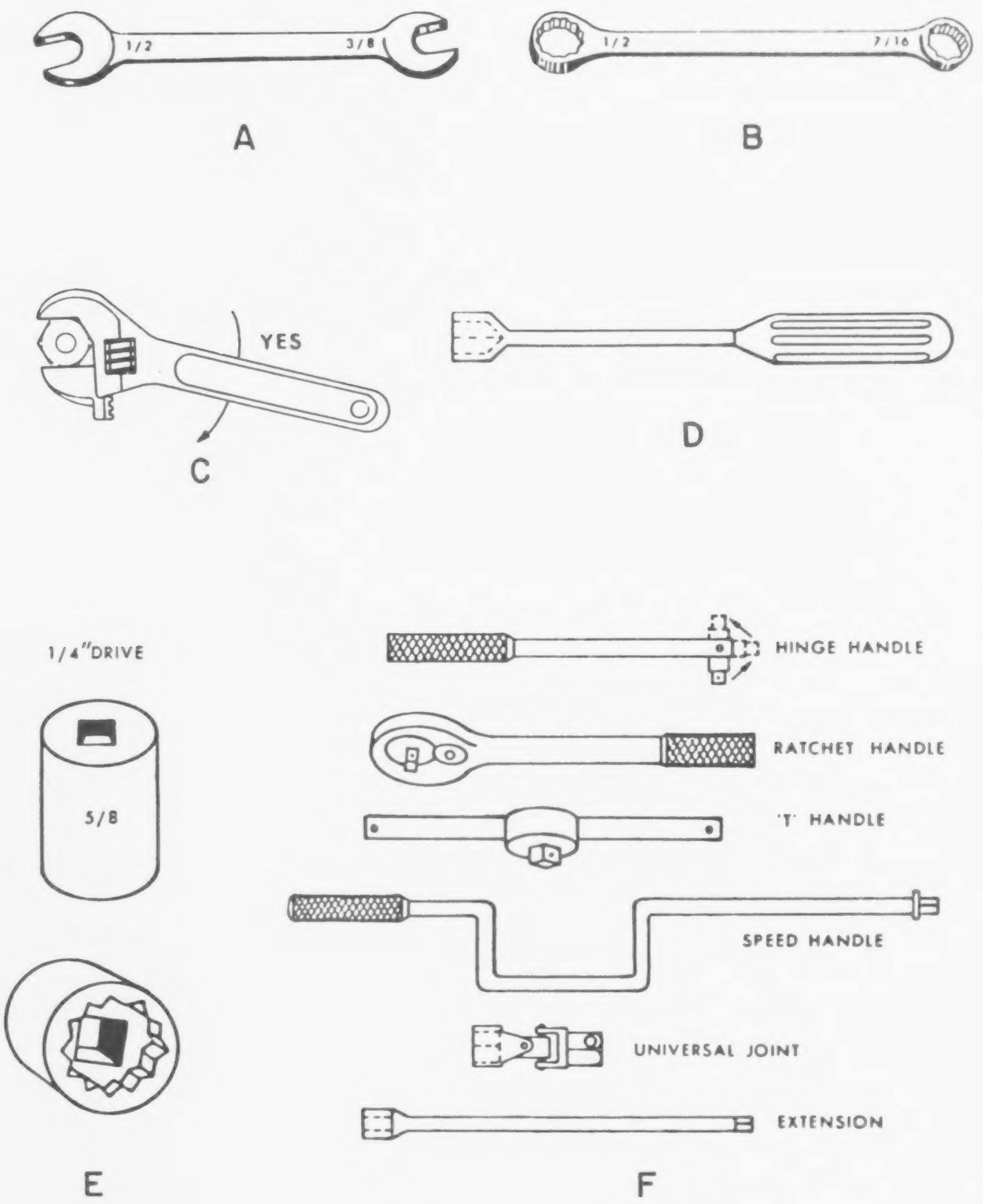

1/2
3/8
A
1/2
7/16
B
YES
C
D
1/4"DRIVE
5/8
HINGE HANDLE
RATCHET HANDLE
'T' HANDLE
SPEED HANDLE
UNIVERSAL JOINT
EXTENSION
E
F

Figure 5–34. Types of wrenches and accessories.

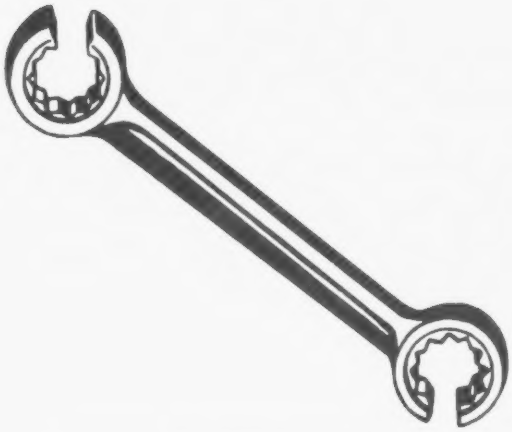


Figure 5–35. Cutaway box-end (tubing) wrench.

on the end that fit into corresponding notches in the nut or plug.

Hex and fluted wrenches. Hex (Allen) wrenches are L-shaped tools (as shown in fig. 5-37) used for inserting and removing set screws which have a hollow, hex-shaped recess. This wrench is available in many different sizes.

The fluted (Bristol) wrench is used for the same purpose as the hex wrench and looks very much like it. Sometimes called a spline wrench, the Bristol wrench has a decided advantage over the hex wrench in that the hex wrench has a tendency to spread the screw recess, whereas the splines on the Bristol wrench prevent the slot from spreading. These wrenches are available with either four or six flutes and in sizes ranging up to 1/4 inch.

Torque wrenches. You need to know how to set and use torque wrenches because you should frequently use them for installing components. Some instrument components and hardware, if not properly torqued, can seriously affect the operation of the system and aircraft. Torque wrenches are calibrated tools used to measure the force being applied when you are tightening nuts, bolts, tubing connections, etc.

Before using a torque wrench, be sure that it is serviceable and has been calibrated within the last 60 days. The ''due'' calibration date will be indicated on a label on the wrench. This may be typed or printed on a strip of plain white paper which is covered with and attached to the torque wrench with cellophane tape. This date may be written as the Julian date or day, month, and year. It may also be written on labeler tape or on an AF Form 394.

Two basic types of torque wrenches are used in the Air Force. They are the flexible beam type and the breakaway or automatic release type.

a. Flexible beam type. The flexible beam type is also referred to as an indicating type of torque wrench because the amount of torque being applied is indicated by a pointer which is read against a scale. Figure 5-38 shows two types of flexible beam torque wrenches. The upper wrench is the deflection-indicating type on which applied torque is read directly from the indicating scale as it moves under the pointer when the exposed beam bends. The lower wrench is the dial-indicating type. The beam, which is inside the housing, moves a pointer which is read against the fixed scale. Normally, flexible beam type torque wrenches are used for holding operations only because scratches and nicks in the beam can affect their accuracy. Also, the pointers are easily bent, and temperatures may affect the flexibility of the beam.

b. Breakaway type. Breakaway type torque wrenches are preferred for applying torque because there is no mistake about when the desired torque is obtained. Breakaway torque wrenches are adjustable; a desired torque can be set (within the limits of the wrench) by turning the handle or grip to settings on the micrometer-type scale. The breakaway type torque wrench automatically releases when this predetermined value is reached.

As shown in figure 5-39, the breakaway torque wrench consists of an adjustable handle (E), a locking ring to prevent accidental changing of the setting (D), a micrometer-type adjustment scale incorporating a movable thimble (C) which is marked with secondary increments, a spring tube (B) which is marked with the primary increments, and a drive assembly (A) which accepts either 1/4, 3/8, or 1/2 inch drive or larger sockets or adapters.

Figure 5-40 is an enlargement of the wrench shown in figure 5-39. You can see that the micrometer-type scale consists of the primary increments etched on the spring tube and the vernier scale (secondary increments) etched on the thimble. Notice that the shaft scale (primary increments) is graduated in 50 inch-pounds. The vernier scale is graduated in increments of 5 from 0 to 50 inch-pounds.

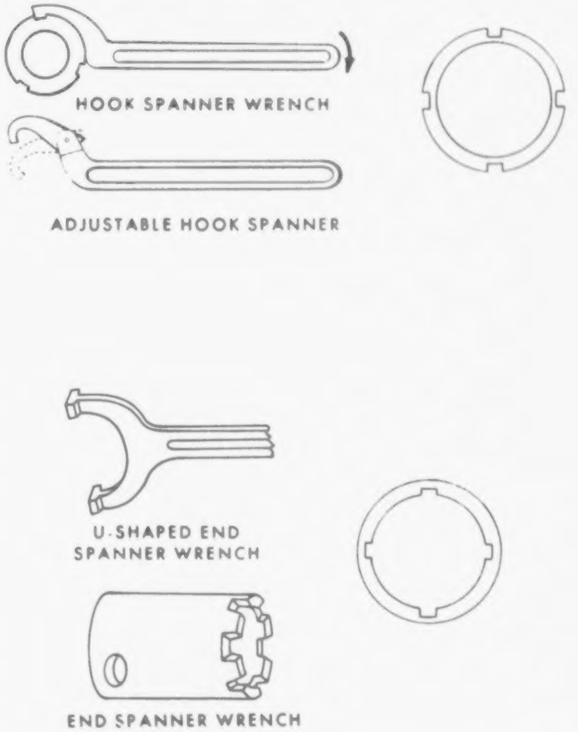


Figure 5–36. Spanner Wrenches.

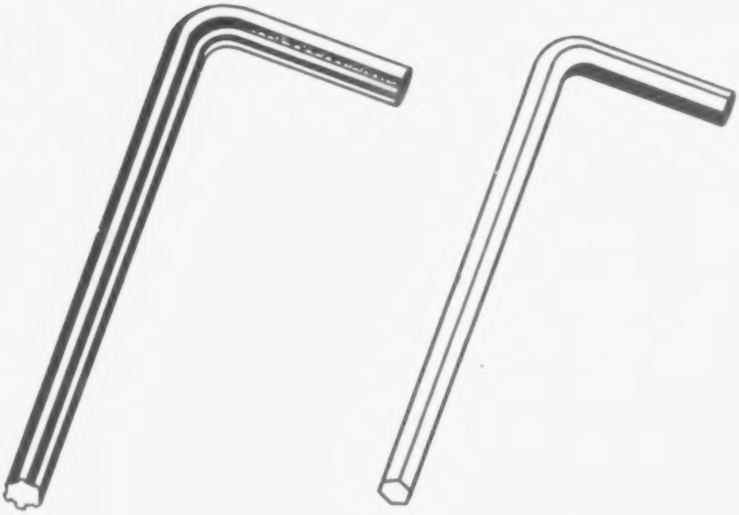


Figure 5–37. Bristol (spline) and allen (hex) wrenches.

To increase the torque setting of the wrench, turn the handle or grip clockwise. To reduce the torque setting, turn it counterclockwise. Turning the handle lengthens or shortens the length of the wrench; it also changes the scale reading of the micrometer-type scale while reducing or increasing tension on the spring inside the handle. The desired torque setting should always be approached from the lower end of the micrometer-type scale.

The breakaway torque wrench has a locking device to insure that the desired torque value does not change when the wrench is being used. Some wrenches are turned to engage the locking of the handle. In other wrenches, locking is done by sliding the lock along the handle to engage a pawl or slot in the shaft. In either case, the grip is prevented from turning when the wrench is in use. The lock must be unlocked before the handle (grip) can be turned. The lock can be locked only when a number on the vernier scale (0, 5, 10, etc.) is in line with the shaft index line.

You can use this wrench almost as you would any other. But be sure to pull the wrench in a clockwise direction with a smooth and steady motion. A fast or jerky motion will result in an improperly torqued nut or bolt. When the torque applied reaches the predetermined torque setting in the handle, the wrench automatically releases (breaks away). You then have approximately 15° to 20° of free travel. The release is distinct and easily detected, and indicates that you have reached the correct torque. This is your signal to release the force being applied to the wrench.

c. Torque wrench precautions. Prior to using any torque wrench, verify that the calibration is current. Make sure that it can be used in the direction in which you need to apply torque. Clockwise (CW) torque wrenches will be marked with single-ended arrows pointing in the clockwise direction and only need to be calibrated in the clockwise direction. Torque wrenches with torquing capabilities in both clockwise and counterclockwise (CCW) directions must be marked with double-ended arrows and calibrated in both directions.

After prolonged storage and at the beginning of each work shift, each torque wrench must be cycled through the release cycle at least four times. This permits the internal mechanism to redistribute a film of lubricant (grease) throughout the working parts. It can be done by adjusting the wrench to a low setting and either using the wrench on the bolt to be tightened or by securing the drive tang of the wrench in a smooth-jawed vise.

Always store the wrench at the lowest torque value etched on the tube. Leaving a wrench set at a high range while not in use will distort the spring and cause inaccurate torque indications during its later use. If the torque wrench

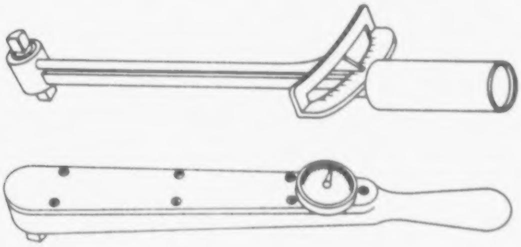


Figure 5–38. Indicating-type torque wrenches.

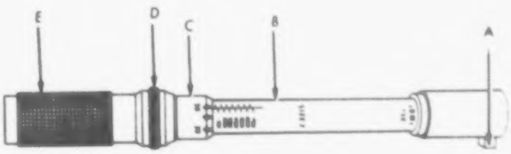


Figure 5–39. Breakaway torque wrench.

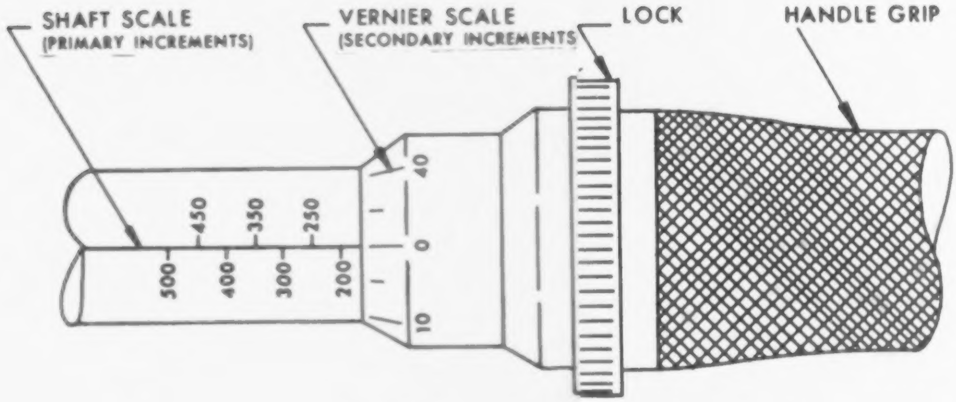


Figure 5-40. Torque wrench reading.

is one that reads 700 to 1600 inch-pounds, it should be turned to exactly 700 (lowest setting).

To obtain accurate reading from the torque wrench, you must observe certain rules. One is to care for the wrench as you would any precision tool. Another rule is to make sure the threads of the nuts, bolts, etc., that will be torqued are in good condition. Threads of bolts and nuts will be clean, dry, and free from oil or grease unless otherwise specified before applying torque.

When using a torque wrench to tighten a series of nuts, never tighten one nut to the specified torque before starting to tighten the other nuts. Instead, tighten each nut a little until they all meet the specified torque. Nuts opposite (or diagonal to) each other should be tightened in sequence. Select proper size and range of torque wrench so that the working range shall not be within the lower 20 percent of the scale. Example: A torque wrench of which the lowest setting marked on the tube is 10 and the highest setting is 200, is considered to have a capacity of 200. The lowest 20 percent of this capacity would be 40 (20% of 200). Normal use of this wrench must be limited to values between 40 and 200.

Do not use a torque wrench to apply a greater amount of torque than the rated capacity of the wrench. Do not use a torque wrench to loosen previously tightened nuts, bolts, fittings, etc.

Do not attempt to change the setting when the handle is in a locked position. Do not place an extension on the square drive to increase the length of the torque wrench unless you have mathematically calculated the torque value to set on the handle. Do not use an extension on the grip end of the handle.

Remember to torque the nut and not the screw or bolt. The technical order torque values are given for the nut. There are cases, however, where it is impossible to torque the nut, and the screw heads or boltheads have to be torqued. In these cases, get the proper value needed to set the torque to the upper limit allowed by the technical order for that specific torque value. To illustrate, assume that the technical order requires a torque of 50 inch-pounds with a tolerance of plus or minus 5 inch-pounds to be applied to a nut and bolt combination. If you could torque the nut, you would want to set the torque wrench at 50 inch-pounds. But since you must turn the bolthead, you should set the torque wrench to 55 inch-pounds because friction is produced when the shank of the bolt expends some of the torque pressure. If you are installing the screw or bolt into a plate nut or into a component threaded hole, use the desired torque setting given in the technical order.

Torque wrenches issued from supply to shops or toolcribs for use in the maintenance of aircraft and other critical equipment should be checked and calibrated at least once every 2 months (60 days). The 60-calendar-day period is to be calculated from the date of the calibration.

NOTE: The calibration may just be an accuracy verification against a standard (torque wrench tester), or it may also require repair and adjustment. Anytime a torque wrench is dropped or otherwise abused, it must be verified prior to further use.

d. Units of measurement. The most common units of measurement applied to torque values are inch-pounds and foot-pounds. If the proper torque value is stated in foot-pounds and you are using an inch-pound wrench, you will have to compute the proper setting for your wrench. To change inch-pounds to foot-pounds, divide by 12. To convert foot-pounds to inch-pounds, multiply by 12. For example, 600 inch-pounds equals 50 foot-pounds, and 50 foot-pounds multiplied by 12 equals 600 inch-pounds.

e. Torque wrench adapters. We have given you the information you need to torque a bolt or other fasteners under normal conditions. However, as is true in most things there are exceptions to the normal rules. Remember that there are two items of equipment you can use which will affect the torque you are applying to the fastener.

f. Extensions. The first item that affects the torque-wrench setting is the extension. Any time you change the length of the torque wrench, you change the torque output. The torque setting has already been determined by the manufacturer of the wrench, who computes it by measuring from the center of the tang (square drive) back to the center of the hand grip. Assume that you are using a torque wrench that measures 12 inches from the center of the tang to the center of the hand grip area, with an extension 6 inches long measured to the center of the extension jaws. The "A" portion of figure 5-41 shows such an arrangement. Further assume that you want to tighten a nut to 300 inch-pounds.

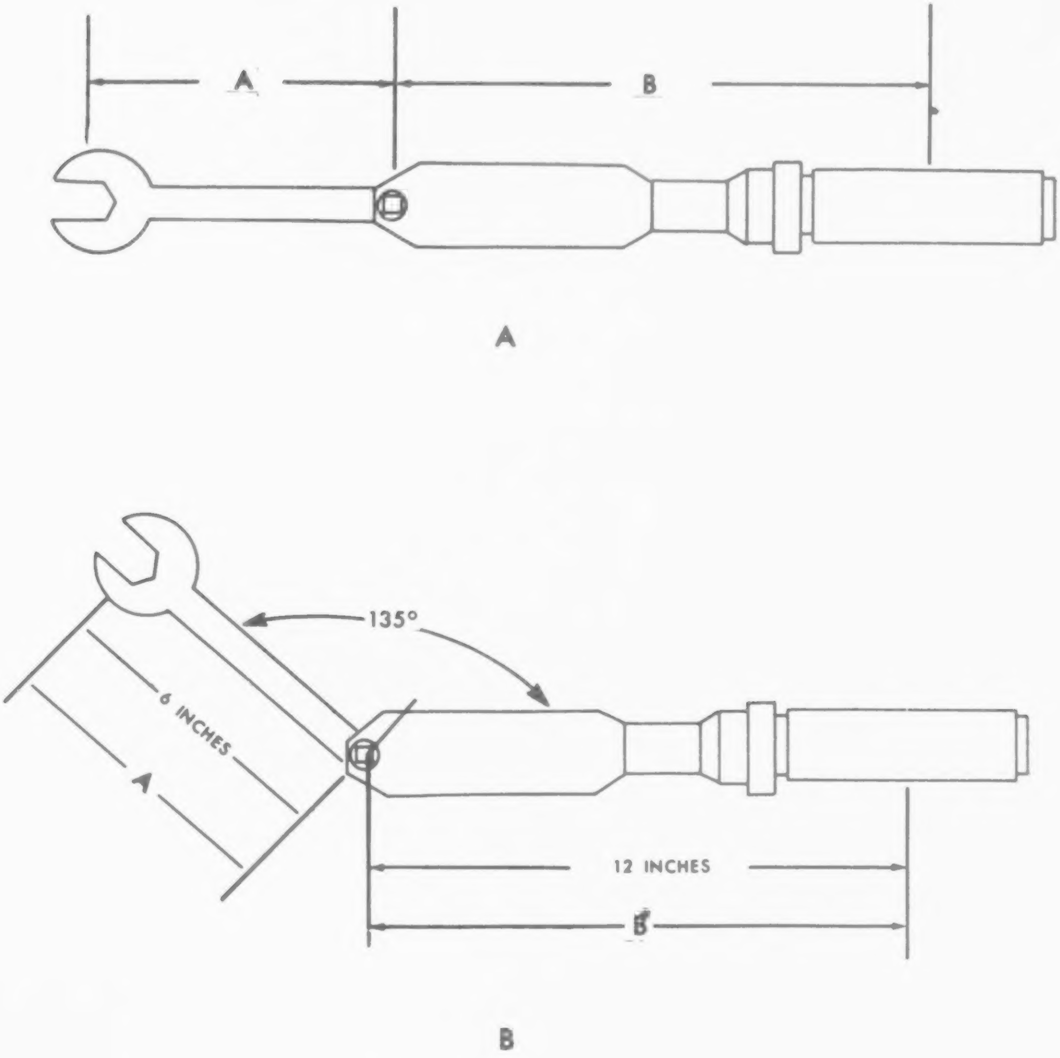


Figure 5-41. Torque wrench extension.

You have created a situation that makes the torque wrench setting invalid because of the length change. You need an acceptable formula to solve your problem. The formula to use is

$$S = \frac{TB}{B + A}$$

S = desired torque wrench setting or reading, T = desired torque to be applied to the nut (300 inch-pounds), B = wrench length between the center of the drive tang to the approximate center of the handle (12 inches), A = the length of the extension (6 inches).

Using the formula,

$$S = \frac{TB}{B + A} \quad S = \frac{300 \times 12}{12 + 6} \quad S = \frac{3600}{18}$$

$$S = 200 \text{ inch} - \text{pounds}$$

The computation shows that to set the torque wrench to apply 300 inch-pounds of torque to the nut, you must set the torque wrench setting at 200 inch-pounds.

When an extension is set at an angle, it also changes the overall effective length, as shown in Part B of figure 5-41. In this case, we use the equation

$$S = \frac{BT}{B - A \cos 3}$$

or for more accuracy

$$S = \frac{(T)(B)(B - A \cos 3)}{A^2 - 2AB \cos 3 + B^2}$$

S, T, B, and A have the same meaning as in the first example. Cos 3 is the cosine of the angle of the extension to the torque wrench. These cosines have been figured for the angles you will normally encounter and are listed in a table in TO 32B14-3-1-101, Torque Indicating Tools.

Therefore, if you desired to torque a nut to 250 inch-pounds (T) using a 6-inch extension (A) that is set at a 135° angle (as shown in figure 5-41,B) to your torque wrench which is 12 inches long (B), you calculate the torque-wrench setting (S) using the first equation as follows:

$$S = \frac{BT}{B - \cos 3}$$

$$S = \frac{BT}{B + 0.7A}$$

$$S = \frac{250 \text{ X } 12}{12 + (.7)(6)}$$

$$S = \frac{3000}{12 + 4.2}$$

$$S = \frac{3000}{16.2}$$

$$S = 185.2$$

If more accuracy is required, use the second formula as follows:

$$S = \frac{(T)(B)(B - A \cos 3)}{A^2 - 2AB \cos 3 + B^2} E$$

$$S = \frac{B^2 T + .7ABT}{A^2 + 1.3 AB + B^2}$$

$$S = \frac{(12)^2(250) + (.7)(6)(12)(250)}{(6)^2 + (1.4)(6)912) + (12)^2}$$

$$S = \frac{36000 + 12600}{36 + 100.8 + 144}$$

$$S = \frac{48600}{280.8}$$

$$S = 173.1$$

This second method is more complex but it is more accurate and requires lower wrench settings than the first method.

Remember, though, because of the chances of inaccurate measurement of lever arm distances, direction of the torquing forces, and errors in calculation, the use of extensions on torque wrench should be avoided when possible. Where the use of extensions is necessary, readings or settings can be accurately calculated as just explained.

Exercises (301):

1. Name the proper wrench to use for the following maintenance actions.

   a. To remove a bolt which is inaccessible to an open-end wrench due to a restricted swing area.

   b. To remove a large nut with the bolt protruding enough to prevent the use of a standard socket.

   c. To remove a set screw which has a recessed hexhead.

   d. To tighten a bolt to a specific tightness value.

e. To remove a highly torqued bolt which is inaccessible to a socket and ratchet.

2. What precautions should you take when using the following wrenches?

   a. All wrenches.

   b. Open-end.

   c. Adjustable.

   d. Torque.

3. Name the two types of torque wrenches.

4. What is the most common type of torque wrench used in the Air Force?

5. How can you tell when a torque wrench is due calibration?

6. How can you determine when a torque wrench was calibrated?

7. If a torque wrench is dropped, what action must be taken?

8. How do you reduce the torque setting on a torque wrench?

9. Torque wrenches must be verified at least once every

10. A specialist has just torqued an aircraft panel down, and the TO states that the screws should be torqued to 350 inch-pounds plus or minus 5 inch-pounds. At what setting should the torque wrench be set and why?

11. Compute the torque wrench settings required from the following information:

Required Torque	*Torque Wrench Length*	*Extension Length*	*Torque Wrench Setting*
a. 288 inch-pounds	9 inches	4 inches	——
b. 100 inch-pounds	12 inches	12 inches	——
c. 400 inch-pounds	18 inches	2 inches	——
d. 300 inch-pounds	12 inches	6 inches	——
e. 100 inch-pounds	12 inches	3 inches	——

302. State the categories and proper uses of hammers.

Hammers. Hammers are generally named according to their shape; e.g., ball-peen, claw, etc. Actually, there are three categories of hammers: hard-faced hammers, soft-faced hammers, and mallets. We will limit our discussion to the two most common types found in an instrument shop, a hard-faced ball-peen hammer and a plastic soft-faced hammer.

Ball-peen hammer. The name of this hammer (fig. 5-42) was derived from the ball-shaped end which is used to peen (expand or stretch) metal. The ball-peen hammer is frequently used to expand the end of a rivet in a hole. The flat-faced end of the hammer is used for tapping punches and chisels or for other rough work.

Plastic hammer. The plastic hammer, shown in figure 5-42, has a head made of plastic. It is intended for use where a steel hammer may mar or break the item being hammered. Since the soft material on the face of these hammers can be damaged easily, they should not be used for rough work such as driving punches, nails, or bolts.

Using a hammer. When using a hammer, you should grip it close to the free end of the handle. Whenever possible, strike the object with the full face of the hammer, with the hammer face parallel to the work. You should make certain that the hammer heads are securely wedged on the handle, and you should make certain that both the head and handle are kept dry and clean. You should also make certain that the face of the hammer is kept free of all foreign matter, since oil, grease, or mud may permit the hammer face to slip off the work and cause damage or injury.

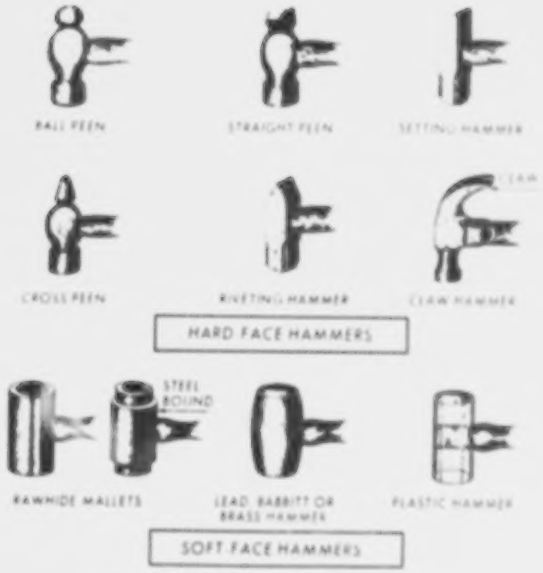


Figure 5-42. Commonly used hammers.

Exercises (302):

1. Name the three categories of hammers.

2. What are the proper uses for ball-peen hammers?

3. On what is a plastic hammer used? Why?

4. What are the three primary causes of hammer accidents?

303. State the uses and abuses of selected files.

Files. A file is a precisely made tool of hardened steel with cutting edges across the surface. It is used for cutting, smoothing, and removing small amounts of metal. The terms commonly used to describe a file are illustrated in figure 5-43.

Types of files. Files come in various shapes, lengths, and grades of cut. The type of work being done will determine which file to use. In selecting a file for a particular job, first consider the shape of file desired.

The *half-round* file is a general purpose file. The rounded side is used for curved surfaces and the flat side for flat surfaces.

Mill files are tapered in both width and thickness. They are used primarily for precision work where a smooth finish is desired. Mill files are available without teeth cut in one edge; this is called the safe edge. The safe edge is included on some files so that when close work is being done, the file will not damage areas adjacent to the work.

Pillar files are used for filing slots and keyways and for filing work in close quarters. One or both of the edges are without cutting teeth (safe edge).

Round files are similar to mill files, except that the cross-section is round. These files are used mainly for enlarging round holes. In the smaller sizes, they are sometimes called rat tail files.

Swiss pattern files are small, delicate files used for work on instruments and delicate mechanisms. They come in kits of 12 files of assorted sizes and shapes, and they should be handled carefully because they break easily.

Files have either single-cut or double-cut teeth. Single-cut files have rows of teeth cut parallel to each other; double-cut files have criss-cross rows of teeth. The single-cut files are for fine, detailed work, and the double-cut files are used for quick removal of metal and for rough work. Files are also graded according to the spacing and size of teeth. These various grades are illustrated in figure 5-43.

Use of files. Do not use a file without a handle because the tang of the file is sharp and can be driven into the hand if the file is suddenly caught on a spur of metal. When using a file, start the stroke with light pressure near the point of the file. As you push the file across the surface, increase the pressure. Do not apply pressure on the return stroke. Each stroke should be slow and steady. Excessive speed causes the file to rock, resulting in rounded corners. Too much pressure bends the file and also results in rounded corners. To obtain a very smooth surface, draw-file the work with a single-cut, smooth file. For filing inside curved surfaces, use a file with a curve most nearly matching the curvature of the work.

Care of files. Files are very brittle and are never to be hammered or used as prying bars. Store files in the proper rack. Never store them in a drawer without separators or wrapping to protect the file surface. Always use these basic rules:

- Keep files dry to prevent rusting.
- Keep the teeth of the file clean. Brush the metal filings from the teeth.
- Never lubricate a file.
- Use the file recommended for the job.

Never use a file when the teeth are "choked" or clogged with particles of metal. You may jar loose filings by lightly bumping the tip of the file or the end of the handle on the work bench now and then. This will not always get all of the chips out, so you should keep a file card handy. When the file gets "loaded," clean the teeth with the file card by drawing the file card and brush (fig. 5-43) back and forth across the file parallel with the cuts. If there are any chips left after using the file card, dig them out with the pointed

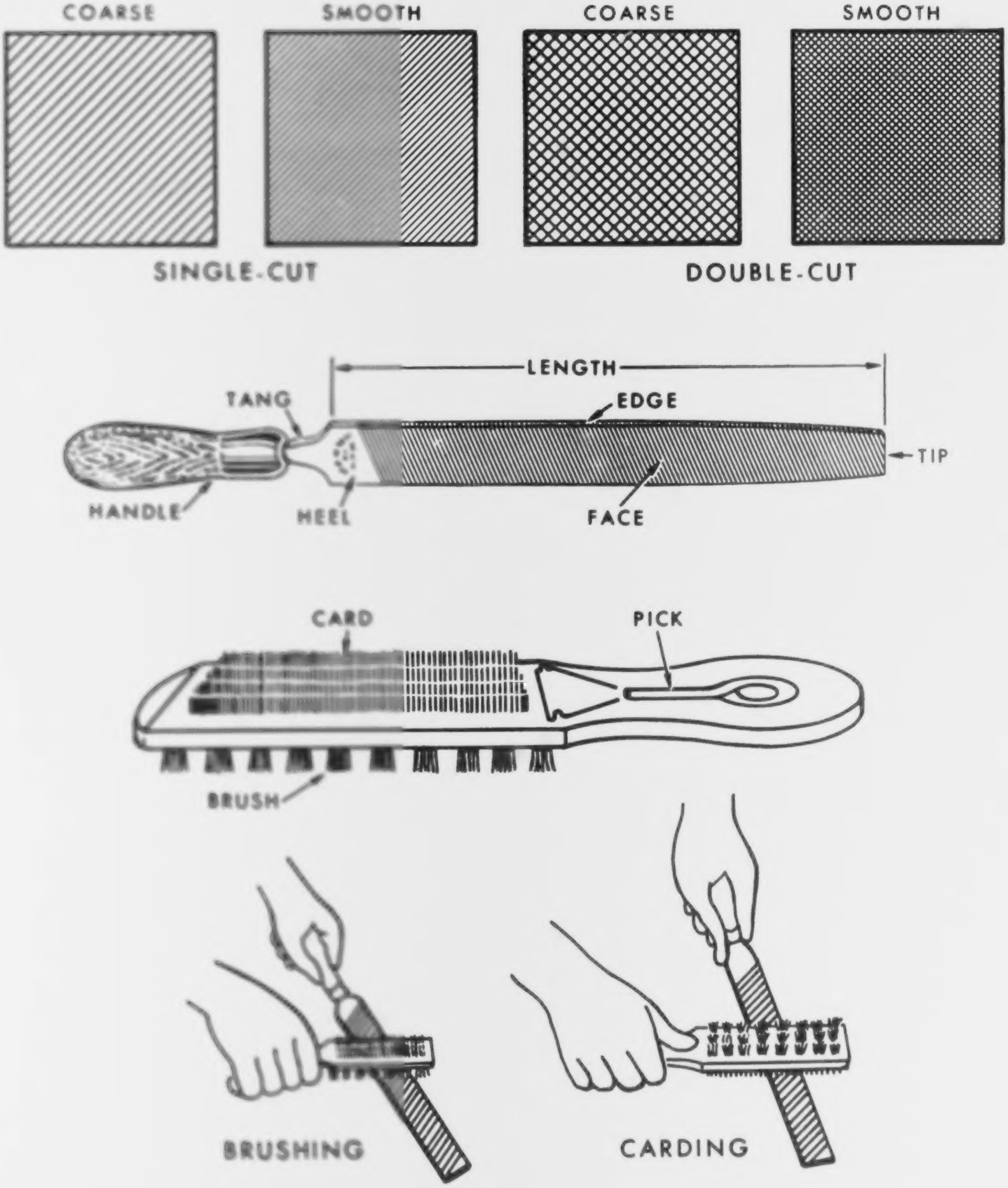

COARSE
SMOOTH
COARSE
SMOOTH
SINGLE-CUT
DOUBLE-CUT
LENGTH
TANG
EDGE
TIP
HANDLE
HEEL
FACE
CARD
PICK
BRUSH
BRUSHING
CARDING

Figure 5–43. Files.

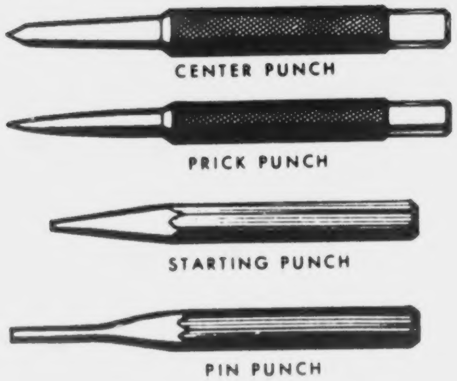


Figure 5-44. Punches.

cleaning wire which is usually kept in the handle of good file cards.

Never use a file on material which is harder than the file. One stroke across such a surface can dull the cutting teeth and make the file useless.

Exercises (303):

1. State the use of the mill file, pillar file, and swiss pattern files.
2. For fine detailed work, you should select a file with what type of cut?
3. Briefly state how to file a surface.
4. How are files stored? How are they cleaned?

304. State uses and misuses of selected punches and drills.

Punches. Punches (fig. 5-44) are used to start holes for drilling, to drive out pins, and to align holes. They are made of carbon steel. The specific uses of some of the punches that you will need in performing maintenance are discussed in the following paragraphs.

Starting punches are used for loosening pins or for knocking out rivets after the heads have been sheared off. Starting punches are designed to withstand heavy blows. The sides of such punches are tapered all the way to the face, which is flat. Because of their tapered shape, you cannot use starting punches to drive pins all the way out of a hole. Once you loosen a pin, drive it the rest of the way out by means of a pin punch. Starting punches are also referred to as taper punches.

Prick punches are used for marking center or other reference points on metal. Such punches have relatively slender bodies and are tapered to a point of approximately 30°.

Center punches. are used to start holes to be drilled. They are identified by their relatively heavy body and a point ground to about 90°.

The *pin punch* is used to complete the job started by the starting punch. The sides of the punch are parallel for an inch or two below the body so that it can completely remove a pin from its hole. The pin punch is not made to withstand hard blows, and you should not use it in place of a taper punch.

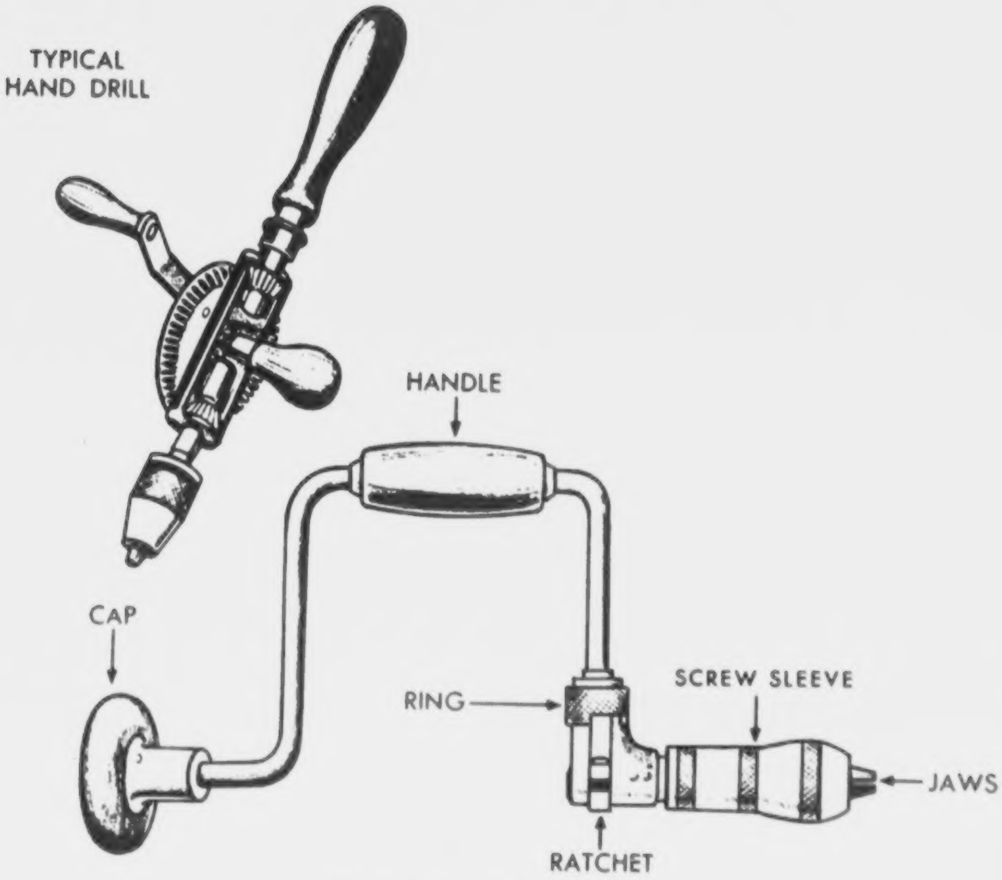
Do not abuse punches—always use the correct punch for the job to be done. For example, do not use a center punch to loosen or drive out a pin, because the pin may spread and freeze in the hole. Also, with improper use, such as striking the punch too hard with a hammer, it is possible for the head of a punch to become mushroomed. When mushrooming occurs, you should grind the head to its original shape before the punch is used again. Otherwise, when striking the punch, you may cause pieces of steel to break off from the mushroomed head, and the flying pieces of steel are capable of causing serious injury, particularly to the eyes.

Hands and Electric Drills. If you ever have to modify any instrument mockups or other equipment, you may have to drill holes to mount parts. You will occasionally need to drill new holes in electrical connectors and pressure fittings in order to safety-wire them.

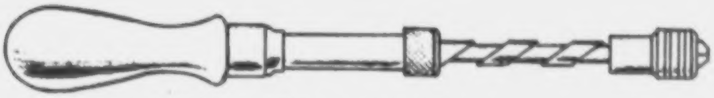
Either a hand drill or an electric drill may be used for this purpose. A hand drill (fig. 5-45) consists essentially of a chuck that is driven by a handcrank, a spin handle, or a push-driven spiral drive. Some hand drills have two gear ratios to permit a variation in cutting speed. The drill bit must be fastened securely in the chuck before use. The portable electric drill serves essentially the same purpose as the hand drill. It is, of course, more convenient to use, assuming that electrical power is available.

The twist drill, also known as a drill bit, is used to cut holes in metal. Twist drills are made of either carbon steel or high-speed steel. Carbon steel drills are suitable for low-speed drilling; but if you use them for heavy work or at high speeds, they heat and lose their hardness. On the other hand, drills made of high-speed steel can become red hot without losing their hardness.

Before using a drill, always start the hole with a center punch. This prevents the drill from wandering. Make sure that the punch mark is well defined. On small work, it is good to place a small block of wood behind the metal. Always fasten the work securely to a table or other work surface, using a vise or clamps. Never hold the work in your hands; if the drill should slip or bind in the hole, serious injuries are likely to result.


TYPICAL
HAND DRILL
HANDLE
CAP
RING
SCREW SLEEVE
JAWS
RATCHET

TYPICAL HAND BRACE



TYPICAL SPIRAL HAND DRILL

Figure 5–45. Hand drills.

When using a hand drill, always place the point of the drill in the mark made by the center punch before turning the crank. Then, with a steady applied pressure, turn the crank at a uniform rate. Maintain a constant angle between the drill and the work, because any side pressure causes the twist drill to bend or break. In using an electric drill, start the motor before placing the point of the twist drill in the punch mark. Following the same precaution as with the hand drill, maintain a steady pressure until the point of the drill begins to break through; then slacken the pressure.

Some materials that you drill will require a special lubricant to prevent the twist drills from becoming overheated. Tool steel requires oil, as does copper. Use oil or soda water for drilling soft steel. Glass may be drilled if turpentine is used as a lubricant. Brass and cast iron do not require any lubrication.

When you store drills, make sure that they are covered by a rust-preventive compound and are placed in racks or compartmented boxes to prevent the cutting edges from being chipped or dulled by contact with other tools.

Exercises (304):

1. What are starting punches used for?

2. What are pin punches used for?

3. What could happen if a center punch were used to remove a drive pin?

4. Briefly explain the hazards presented by mushroomed heads on punches.

5. Why must the type of drill bit be considered when doing heavy work?

6. Briefly explain how to drill a hole in a large metal chassis using an electric drill.

7. What lubricant should you use when drilling copper? Tool steel? Brass? Soft steel?

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ANSWERS FOR EXERCISES

CHAPTER 1

Reference

200 – 1. To prevent them from becoming wasteful and careless.
200 – 2. AFR 67-10.
200 – 3. The individual who signed for the tool box and its contents. The Air Force retains ownership of the property.

201 – 1. The wing commander has command responsibility for all equipment assigned to the wing. When a squadron maintenance truck is being used to carry people to the base exchange, that squadron commander has not accepted his or her full responsibility. Therefore, maybe this responsibility should be reassigned to someone else, such as the transportation officer.
201 – 2. By issuing timely instructions and directives.

202 – 1. A person who supervises property in any manner assumes supervisory responsibility for that property.
202 – 2. When the commander directly supervises Air Force personnel working with Air Force property.

203 – 1. Any time Air Force equipment is in your possession.
203 – 2. You must stop, pick up the boxes, and contact the supply unit so that they may recover the boxes.

204 – 1. The condition of the property.
204 – 2. Pecuniary liability.
204 – 3. Turn-in of the property, and transfer of the property to another individual.

205 – 1. Turn-in of parts, whether serviceable or reparable, relieves you and your supervisor of the responsibility for those parts.
205 – 2. By turning in those chairs to supply for reissue, the responsibility and accountability of them is transferred.
205 – 3. The ranking person assigned would have to assure responsibility for the supply account.

206 – 1. Pecuniary liability means that the person responsible for lost or deliberately misused and damaged equipment must pay for it.
206 – 2. The cash collection voucher and the statement of charges.
206 – 3. It indicates that pecuniary liability has been admitted.
206 – 4. The price of $200 listed at the top of a statement of charges form is the actual cost of the item. The $185 at the bottom of the form indicates present value due to depreciation.
206 – 5. The person (1) acknowledges liability, (2) authorizes a payroll deduction, (3) waives personal rights, (4) affirms liability, and (5) agrees to pay for the article.

207 – 1. The report of survey explains and records circumstances involving lost, damaged, or destroyed Air Force property.
207 – 2. The individual that has custodian responsibility at the time of loss.
207 – 3. Within 30 days.

208 – 1. The major commands and the allowance and authorization sections.
208 – 2. The type of aircraft, the number of aircraft maintained, the size of the workload, the type of maintenance to be done, and the climatic conditions.
208 – 3. To prevent delays in maintenance.
208 – 4. The bench stock support unit.

209 – 1. AFR O-10.
209 – 2. Systems Support.
209 – 3. TAs 401 through 650.

210 – 1. TA 365, Part D. The sections listed under Part D are for the individual shops under this heading.
210 – 2. In the front of the TA.
210 – 3. The Allowance Summary.

211 – 1. TA 729.
211 – 2. The part, section, and subsection of the TA in which that equipment authorizations are listed. In the instructions for the TA.
211 – 3. By referring to the instructions for the TA.

212 – 1. The first four digits of the NSN are the Federal Supply Classification code. The first two digits are the FSC group, and the last two digits are the FSC class within that group.
212 – 2. It precisely identifies individual items.
212 – 3. Manufacturer's part numbers, drawing numbers, model numbers, type numbers, source control numbers, and specification control numbers.
212 – 4. To screen items procured by agencies of the Federal Government to prevent duplication.

213 – 1. To speed up identification of parts in supply channels.
213 – 2. It indicates the kind of information contained on the film.
213 – 3. (1) d.
  (2) a.
  (3) b.
  (4) c.
  (5) c.
213 – 4. 5330-00-559-2363.
213 – 5. The unit of issue is each (EA), and the cost is $2.08 each.

214 – 1. DD Form 1348-1.
214 – 2. The issue order is killed, a request for the item is sent off base to depot or another base and a due-out is established.
214 – 3. That the item is issued immediately and the necessary information is put into the computer at a later time.

215 – 1. Low cost, expendable items which, due to repeated use, are placed at the point of use before they are actually needed.
215 – 2. Each week.
215 – 3. 30 days or less.
215 – 4. The weapon system initial supply stocklist and a stocklist from an organization with a like weapon system.
215 – 5. Materiel Control and the bench stock branch of Base Supply.

216 – 1. That the computer recommends that the item be deleted from bench stock.
216 – 2. A bin sequence serial number assigned to the item.
216 – 3. The number of months after the date of manufacture that an item can be used.
216 – 4. At least quarterly.
216 – 5. Security code J.
216 – 6. (a) Should be deleted, (b) 01, (c) 235, (d) pound (lb), and (e) 4 lbs.

217 – 1. To provide a continuous account of all parts and supplies that have been ordered by your section.
217 – 2. A QRL is a quick reference list which provides maintenance personnel with a speed; identification of frequently needed parts. It also provides a fast means of communicating identification data to supply.
217 – 3. (1) activity code, (2) organization code, (3) shop code, (4) Julian date, and (5) request serial number.
217 – 4. It identifies the method of location (branch of Base Supply) used to process an issue or turn-in request.
217 – 5. Activity code "R" identifies a routine request. Activity code "X" identifies an expedite type of request.
217 – 6. From your technical order reference or QRL.

218 – 1. The type of transaction you are conducting with Supply.
218 – 2. That the job cannot be completed until the requested part is received.

219 – 1. Make them by radio or telephone. Give the information as documented on the AF Form 2413.
219 – 2. Deliver them to demand processing along with a DD Form 1348-6, non-NSN requisition.

220 – 1. Test equipment.

221 – 1. a. To identify serviceable material.
  b. To identify reparable material.
  c. To identify condemned material.
221 – 2. A properly completed DD Form 1574 with the serial number in the Serial Number/Lot Number block.
221 – 3. A properly completed DD Form 1577 (red tag) to the unit.

222 - 1. Can (CN).

222 - 2. DUO.

222 - 3. Carbon removal compound, stock number 685-00-803-6420.

223 - 1. Priority monitor reports.

223 - 2. DIFM listings.

223 - 3. To verify that all items on order are still needed.

CHAPTER 2

224 - 1. (1) The collection process—data are written on AFTO Forms 349 and processed on magnetic tape; (2) the storage process—25 months of historical data from processed AFTO Forms 349 are provided; and (3) the retrieval process—the data can be retrieved as requested by using agencies and commands.

224 - 2. a. Production data are provide on what was done, who did it, and on what it was done.

b. Productive labor data are provided on both in-house and loaned labor.

c. Cost of maintenance data are provided by MCS on the cost of man-hours and equipment maintenance.

224 - 3. a. Data are used by AFLC to identify reliability problems on equipment.

b. Data are used by AFLC to identify safety deficiencies and to monitor their corrective actions.

c. Data are used by AFLC to determine TCTO kit needs and TCTO rescission dates.

d. Data are used by Manpower and MAJCOMs to validate manpower needs.

224 - 4. MDC helps decisionmakers at all levels through the use of factual information.

225 - 1. 100 percent.

225 - 2. The work center supervisor.

225 - 3. Each individual.

226 - 1. MDC Daily Transaction Error Listings and MDC Daily Transaction Error Cards.

226 - 2. The work center supervisor corrects and annotates the error listing and returns it to Production Analysis.

226 - 3. The MDC Daily Transaction Error Listing.

226 - 4. Production Analysis specialists and work center supervisors must make continuing periodic spot checks of the MDC Daily Transaction Listing.

226 - 5. The MDC Daily Transaction Summary.

226 - 6. Sections A and B of the MDC Monthly Transaction Listing.

226 - 7. To predict future requirements for parts.

226 - 8. The MDC Work Summary, Part 1.

226 - 9. A summary of all direct labor hours expended by each work center.

227 - 1. Most of the scheduled training time was used in the month of August. Approximately 134 hours were scheduled, and approximately 128 hours were used.

227 - 2. A circle graph, called a pie graph.

228 - 1. Job number 431 on 15 February.

228 - 2. One.

228 - 3. Under the TCTO JCN.

228 - 4. Under a new JCN.

228 - 5. No.

229 - 1. The first part identifies the general type of equipment. The second part identifies the specific type of equipment.

229 - 2. They identify Air Force equipment for reporting and control procedures.

230 - 1. (1) On-equipment—maintenance on end items of equipment. (2) Off-equipment—maintenance on assemblies, subassemblies, or components apart from the end item of equipment. (3) Indirect labor—hours expended for leave, details, compensatory time off, training, and alert duty.

230 - 2. a. Bench checks are off-equipment, are MDC, and you use AFTO Forms 349 to document them.

b. Removal of components is on-equipment, is MDC, and the AFTO Form 349 is used.

c. Identifying the reason for dispatch is on-equipment but is not MDC data. Use AFTO Form 349 or 349-3.

d. Documenting a delayed discrepancy repair action is on-equipment and is MDC data. Use AFTO Form 349-3.

e. The source document for identifying NRTS actions to off-base repair facilities is off-equipment, not MDC data, and the AFTO Form 350 is used.

f. Historical records include on-equipment and off-equipment maintenance actions. They are non-MDC documentation, but the information comes from AFTO Forms 349.

g. The tagging of reparable items is on-equipment, and non-MDC, and the AFTO Form 350 is used.

231 - 1. To simplify recording procedures, minimize the amount of space used for recording information, and permit data retrieval.

231 - 2. A five-character code used to identify a section to which specialists are assigned or to which they may be dispatched to perform work.

231 - 3. When a work center performs maintenance on its own equipment.

231 - 4. Like the off-equipment ID, the on-equipment ID is interpreted by the computer into owning work center and SRD code, but it also is interpreted into equipment serial number, registration or part number, and, as applicable, the mission design, series, or end item WUC.

231 - 5. One-character codes used to identify the type of work done. For example, the letter "T" is the type maintenance code for TCTOs.

231 - 6. A support equipment WUC identifies the type of equipment or end item of equipment, and a support general WUC identifies tasks of a general nature.

231 - 7. An action taken code is a one-character code used to describe the maintenance action that was done.

231 - 8. No. Because some of the codes apply to only certain types of equipment.

231 - 9. The action taken, when discovered, and how malfunctioned codes.

231 - 10. "1" and "3" for civilians.

231 - 11. When maintenance is performed on transient aircraft or on equipment which does not have an ID number assigned.

231 - 12. By a computer program.

231 - 13. The employee number of the team supervisor or senior individual.

232 - 1. You will insure that an AFTO Form 350, Part II, is documented and processed as a no demand transaction through Production Control to Supply.

232 - 2. You will insure that the attached AFTO Form 350 is processed through Production Control.

232 - 3. AFTO Form 349 and AFTO Form 350 is required.

232 - 4. AFTO Form 349 and AFTO Form 350.

232 - 5. Blocks 1, 2, 3, 26, and 27; and columns A, C, D, E, F, G, H, I, J, K, and N.

232 - 6. Blocks 1, 2, 5, 19, 20, 26, and 27.

232 - 7. Columns A, C, D, E, F, G, H, I, J, K, and N.

232 - 8. One line would be completed by the first crew, another line would be necessary for the second crew to show start/stop times and crew size, and a third line would be necessary to show the change in labor category.

232 - 9. One line would be necessary to show time spent on the job up till the crew size changed. Another line would have to be used to show the new crew size. A third line would be necessary to show the change in labor category, unless the crew size and labor category changed at the same time; therefore, either two or three line entries would be needed.

232 - 10. Blocks 1, 2, and 3 and columns C, H, I, J, K, and N, using separate action lines for each category of labor.

233 - 1. No.

233 - 2. The ID number or the serial number; mission, design, series; and equipment classification code (standard reporting designator).

233 - 3. The job control section.

233 - 4. Only when the form is used to dispatch personnel to another location.

233 - 5. That a specialist is required at the location shown in block 9 at 9 o'clock in the morning.

233 - 6. An estimation of how long the job is expected to take.

233 – 7. The work unit code entered in column C.

234 – 1. From the corresponding blocks of the AFTO Form 349.
234 – 2. The national item identification number (NIIN) in block 11.
234 – 3. When a demand has been placed on Supply for a replacement item, the supply document number is entered in block 13 of the AFTO Form 350.
234 – 4. In block 15.
234 – 5. The Reparable Processing Center is responsible for making all entries in block 29 of the AFTO Form 350 except for the DATE REMOVED, which the worker enters.

235 – 1. For control purposes.
235 – 2. Reparable item processing center and repair cycle support unit.
235 – 3. Production control controls, schedules, and routes repair cycle assets to the shop which repairs the item.
235 – 4. Supply point stocks are restricted to selected repair cycle assets peculiar to the maintenance shops being supported.

236 – 1. Items with ERRC (equipment reparability/recoverability code) codes "XD" and "XF."
236 – 2. Job standards furnished by production analysis.
236 – 3. DD Form 1348–1 (copies 3 and 4) and Part II of the AFTO Form 350.
236 – 4. Any change in the number of in-shop specialists available or any change in the status of test equipment, etc.
236 – 5. (1) Items may be picked up directly from the supply points. (2) If the new item needed is back ordered, the reparable item will receive priority in-shop maintenance. If the item is repaired, the due-out is cancelled. (3) if the reparable item is repaired with no demand made on Supply, appropriate paperwork is documented to show consumption for demand levels and logistics.

237 – 1. Sign and print your last name on the DD Form 1348–1, and obtain copy 2 of the form from the Supply representative.
237 – 2. For critical items, 24 hours; for noncritical items, 10 days.
237 – 3. Part II of the AFTO Form 350 is used by Production Control for in-shop scheduling. Part I is used for documenting repair action and for tagging the repaired item.
237 – 4. The Production Control supervisor reviews the suspense copies of DD Form 1348-1 to insure that reparable items are turned in for processing and screens the DIFM listing to insure that the location of each DIFM asset is known.

238 – 1. "Fill or kill" or "fill or backorder."
238 – 2. One AFTO Form 349 will be Action Taken coded "C" and processed by the shop for MDC. The other one will have "C" entered in block 14 and will be forwarded to Production Control along with the AWP item.
238 – 3. AFTO Form 350 (Parts I and II), AFTO Form 349, and DD Form 1348–1 (copies 3 and 4).
238 – 4. The AWP monitor will submit a request to Supply for the status of the parts or for the next higher assembly.
238 – 5. Supply will instruct that the item be returned to the maintenance shop to be prepared for turn-in.
238 – 6. Supply.
238 – 7. They will be turned in to supply or returned to the appropriate shop if authorized as bench stock.

239 – 1. TO 00–35D–54.
239 – 2. To identify maintenance material, design, and quality deficiencies so that action can be initiated to correct and prevent them.
239 – 3. A Category I MDR is a report of an emergency condition pertaining to safety on all types of equipment. Category II is a report of deficiencies of those items that do not have a safety impact.

240 – 1.
  a. The originating point of an MDR is the person who discovers the deficiency.
  b. Screening points are the agencies that review MDRs to insure that they are correctly reported and correctly routed.
  c. The action point is the agency responsible for resolving the MDR.

240 – 2. Quality Control and the Chief of Safety screen Category I MDRs. QC screens category II MDRs.
240 – 3. QC prepares your MDR on a Joint Messageform, assigns and logs in the control number, and submits the MDR for electrical transmission.
240 – 4. Within 72 hours for a Category I report, and within 15 work days for a Category II report.

241 – 1. QC, Supply, or another command-designated activity.
241 – 2. You can bench check the item to the extent of determining that the item is defective. Normally, the item should not be disassembled nor any repair made; but where repair capability exists, it may be more cost effective to go ahead and repair the item. An MDR should be submitted anyway.
241 – 3. AFTO Form 114. In block 6, enter information that will assist in identifying the exhibit and enter "Critical Item," if applicable.
241 – 4. Pending disposition instructions, the holding activity will hold the MDR exhibit for a maximum of 24 workdays. Follow-up action will be initiated if instructions are not received within 20 workdays. If the 25 workday limit passes, the MDR exhibit will be processed according to its condition.
241 – 5. Because they can save both time and money.
241 – 6. The screening point in corporation with the appropriate ALC.

242 – 1. AFTO Form 781A.
242 – 2. To document maintenance status and show the status and history of inspections that relate to the daily flying activity.
242 – 3. To provide a record of inspections (other than daily or preflight), TCTOs, and delayed discrepancies.

243 – 1. The equipment is not operable if the main transformer begins to smoke when power is applied; therefore, the red X symbol best describes the condition.
243 – 2. A circled red X indicates that the aircraft or equipment is not to be used until an urgent action TCTO is complied with.
243 – 3. Red dash.
243 – 4. That a defect exists but is not serious enough to discontinue use of the equipment.

244 – 1. To document discrepancies and maintenance actions on aircraft.
244 – 2. The supply document number.
244 – 3. Your first name, initial, last name, grade, and employee number in the INSPECTED BY block and your last name initial over the red X symbol.

CHAPTER 3

245 – 1. AFR 66–1, *Maintenance Management*, covers the traditional centralized maintenance concept. AFR 66–5, *Production Oriented Maintenance Organization*, is a decentralized, despecialized concept of maintenance.
245 – 2. In the AFR 66–1 concept.
245 – 3. To meet the peculiar combat needs of the tactical air forces.
245 – 4. Because of the different locations, aircraft, and types of missions.
245 – 5. By allowing them to deviate from the traditional specialization of personnel and to use available airmen for any job they are capable of handling.

246 – 1. The quality control section of AFR 66–1 and the quality assurance program of AFR 66–5.
246 – 2. To inform responsible personnel of defects which need to be corrected by eliminating their causes.

247 – 1. That the number of aircraft scheduled to fly the next day is more than the unit can prepare for flight in the time given.
247 – 2. The skill levels, experience, and number of available personnel, along with the condition and amount of available equipment.
247 – 3. 12 hours.
247 – 4. Under unusual circumstances, such as working at a remote duty location, you may be required to work 16 hours with a 12-hour rest-period following each 16 hour shift.

248 – 1. The maintenance production element of equipment maintenance provides data inputs to the technical element of maintenance engineering.
248 – 2. The actual performance of equipment maintenance and related acts such as servicing, repairing, testing, overhauling, modifying, calibrating, inspecting, and configuring.

248 – 3. Professional and quality maintenance and strict adherance to technical orders.

248 – 4. Maintenance Officers and NCOs.

249 – 1. The main position in each level of command—especially the uppermost level.

249 – 2. It should be the largest one on the chart.

249 – 3. Below the rectangle which represents the unit or person they serve.

249 – 4. The duties and functions of sections or individuals making up a unit.

249 – 5. Unit positions and general outlines of the duties to be performed in those positions.

249 – 6. They help clarify where each individual fits into the unit, to whom each person is responsible, and for whom each person is responsible.

249 – 7. Block 2 should be the largest block because it represents the person or section around which the chart is centered. Both of the 4c blocks should be the same size but smaller than 3c because they are subordinate to 3c.

250 – 1. Leadership, management, and administration.

250 – 2. The DCM is the executive manager of the maintenance organization.

250 – 3. The DCM uses several staff agencies to control, schedule, and monitor maintenance and inspections performed by all shops in the maintenance complex.

250 – 4. (1) Management Support, (2) Quality Control, and (3) Maintenance Control.

251 – 1. (1) c.
  (2) b.
  (3) a.
  (4) c.
  (5) a.
  (6) b.
  (7) b.
  (8) a.
  (9) d.
  (10) d.

251 – 2. The staff agencies (management operations and offices) that are not directly involved in actual maintenance production.

252 – 1. Quality control.

252 – 2. (1) a.
  (2) g.
  (3) e.
  (4) d.
  (5) b.
  (6) b.
  (7) c.
  (8) c.
  (9) e.
  (10) a.
  (11) d.

253 – 1. (1) a.
  (b) c.
  (3) c.
  (4) b.
  (5) a.
  (6) b.
  (7) a.

254 – 1. a. AMS.
  b. OMS.
  c. FMS.
  d. MMS.
  e. AMS.
  f. MMS.
  g. OMS.

254 – 2. a. Mission systems.
  b. Mission systems.
  c. AFCI.
  d. Mission systems.
  e. AFCI.
  f. Mission systems.

255 – 1. (1) The Aircraft Generation Squadron, (2) the Component Repair Squadron, and (3) the Equipment Maintenance Squadron.

255 – 2. AGS.

255 – 3. How to perform general tasks such as towing, jacking, and washing aircraft.

255 – 4. Component Repair Squadron.

256 – 1. To provide individuals with the ability to perform selected jobs in a different AFSC.

256 – 2. Under CUT, the minimum proficiency level you would be trained to in AFSC 325X0 is 2b, but higher levels of proficiency, such as 3c, are authorized and even encouraged.

256 – 3. You may NOT be given cross-utilization training. All individuals must be at the 5 skill level or higher in their primary AFSC to be trained for cross-utilization in another AFSC.

256 – 4. On the cross-utilization specialty training standard (STS).

257 – 1. (1) Organizational, (2) intermediate, and (3) depot.

257 – 2. Intermediate.

257 – 3. (1) c.
  (2) a.
  (3) c.
  (4) b.
  (5) a.

258 – 1. (1) Periodic, (2) phased, and (3) isochronal.

258 – 2. Before flight.

258 – 3. To determine if the aircraft is properly prepared for flight and to make sure no defect exists which could cause an accident or mission abort (cancellation).

258 – 4. When an aircraft has landed and must immediately take off again.

258 – 5. In the periodic inspection concept, the periodic inspection is the most thorough inspection of the aircraft. In the phased inspection concept, the phased inspection is the most thorough and searching. In the isochronal concept, the major inspection is the most thorough and searching.

258 – 6. To reduce the time an aircraft is out of commission (and cannot be used) for any given inspection.

258 – 7. Preflight and throughflight.

258 – 8. Inspections at equal terms or recurring at regular intervals. This helps, not only with scheduling the inspections, but with keeping aircraft available for scheduled flying.

259 – 1. Because the skill and teamwork of inspection personnel determine the quality of the inspection.

259 – 2. Adequate heat, illumination, ventilation, and communications. The location should be accessible to supporting shops.

259 – 3. As applicable, 6 inspection workcards, technical orders, and work unit code manuals (–06s); adequate hand tools and special tools; bench stock items and necessary lubricants; and AFTO Forms 349.

259 – 4. (1) a.
  (2) c.
  (3) c.
  (4) b.
  (5) a.
  (6) d.
  (7) c.
  (8) a.
  (9) b, c, and d.
  (10) d.

CHAPTER 4

260 – 1. (1) d., g., i.
  (2) b., d., g., h.
  (3) a., d., e.
  (4) i.
  (5) f.

261 – 1. Opportunity.

261 – 2. Recognition.

261 – 3. Opportunity.

261 – 4. Belonging.

262 – 1. By recognizing those differences, making allowances for them, and treating each person as an individual.

262 – 2. In order to help them get job satisfaction and effectively deal with them.

263 – 1. No. Every person responds best to a personalized technique which is appropriate to the situation.

263 – 2. Not necessarily. However, the supervisor should at least find out if the worker is bothered by something and could use some help.

263 – 3. With a pat on the back and/or praise for the worker; a letter of appreciation, commendation, and other incentive awards; recommendations for promotion, upgrading, and better assignments.

263 – 4. Through personal contact, written notices and bulletins, or informal meetings and discussions.

263 – 5. (1) Let each worker know where he or she stands, (2) give credit when and where due, (3) keep workers informed, (4) encourage workers' participation, and (5) gain workers' confidence.

264 – 1. A supervisor who is a leader favors positive motivation (reward); one who is a driver has a tendency to favor negative motivation (fear).

264 – 2. To accomplish the mission.

265 – 1. Foresight directed toward the manipulation of future developments so that they will serve the desired purpose.

265 – 2. (1) Visualizing the finished job and the whole procedure involved in reaching that goal, (2) comparing a projected undertaking with past similar experiences, (3) insuring that all diversified activities will be coordinated and directed toward the same goal, and (4) checking the plan for possible strengths and weaknesses.

266 – 1. (1) Duty analysis, (2) developing an organizational chart from the analysis of duties, and (3) assigning personnel to positions.

266 – 2. It will clearly show where people fit in the organization, to whom they are responsible, and who is responsible to them.

266 – 3. (1) Unity of command, (2) span of control, (3) functional grouping or logical assignment, and (4) Delegation of authority.

266 – 4. By assigning selected personnel as subordinate supervisors, each responsible for a few of those people. By controlling those subordinate supervisors, the shop chief can use them to control the whole shop.

266 – 5. You have violated the fundamentals of unity of command.

266 – 6. Logical assignment (functional grouping) has been violated.

266 – 7. You have not really delegated to Sgt Jones the necessary authority to train those apprentices.

267 – 1. Skill level and experience, job priority, and work distribution.

267 – 2. Work that is a challenge.

267 – 3. Carelessness and unhappiness. Morale and discipline problems result.

267 – 4. Rotating duty assignments helps maintain workers' interest. It broadens their experience and insures that someone is always available to can handle any task that comes up. It helps prepare people for promotions and other responsibilities.

267 – 5. Ed, who lacks experience on the job, should be assigned to the job in order to broaden his experience.

267 – 6. The Specialist Planning Chart and the Specialist Dispatch Control Log (AF Form 2430).

267 – 7. To highlight start and stop times.

267 – 8. By extending the time line in red.

267 – 9. It is destroyed at the end of the day if its purpose has been served.

268 – 1. The guiding of people in what to do, how to do it, and when to do it through the use of commands, orders, oral and written communications, etc.

268 – 2. Situations and individual personalities.

269 – 1. When it is necessary to give short simple directions, to supplement a written direction, to stimulate interest, explain why, or give an opportunity for questions.

269 – 1. (1) Nothing is overlooked, (2) written directions can be used as a checklist while work is being done, and (3) they can be used as a firm record in order to hold people strictly accountable.

269 – 3. Oral directions can be very helpful in fully explaining or clarifying the written directions.

269 – 4. The questions of What? Why? Where? Who? How?

270 – 1. Because people react to attitudes. A supervisor must believe that the work is important if he or she expects to instill that attitude in the working force.

271 – 1. Coordination.

271 – 2. Coordination with others of the same rank or authority.

271 – 3. Upward coordination.

271 – 4. By following instructions and doing each assigned task well.

272 – 1. Standards of performance.

272 – 2. All functions of management.

272 – 3. By letting you know exactly what is expected of you.

273 – 1. (1) Determine the task; (2) analyze it for reasonable time, manner, quantity, and quality requirements; (3) obtain agreement or approval of fellow supervisors, the workers, and the boss; and (4) set up the specific requirements.

273 – 2. Performance standards help a supervisor obtain production from workers and estimate future work capacity. They provide data for planning, organizing, and assigning work. They aid in determining who needs additional training, and they provide a sound basis for personnel actions and formal ratings.

273 – 3. Performance requirements let workers know exactly what their jobs are and how their performance will be judged. They let the workers know how much they have to do in a given time, the quality expected, and the manner in which a job should be done.

274 – 1. (1) You will like some people better than others. (2) You will have pride in your unit. (3) You will find that it is easier to rate high than it is to rate low. (4) You will remember unusual performance longer than you will remember typical performance. (5) You will tend to apply a general impression of a strong or weak quality to other areas.

274 – 2. (1) The ability to develop and apply realistic standards, (2) sound judgement, (3) ability to communicate accurately and effectively, and (4) a balanced personality.

274 – 3. Observing, evaluating, and reporting.

275 – 1. AF Form 909.

275 – 2. The individual's grade at the closing date of the reporting period.

275 – 3. At least once a year or when there is a change in reporting official, whichever is sooner.

275 – 4. All of the duties of the individual during the period of the report.

275 – 5. (1) Performance of duty, (2) human relations, (3) learning ability, (4) self-improvement areas, (5) adaptability to military life, (6) Bearing, and (7) behavior.

275 – 6. The overall evaluation.

275 – 7. Facts and specific achievements, your strengths or strong points, recommended improvement areas, your educational and training accomplishments, and other meaningful areas not previously covered.

275 – 8. Anytime after it has been entered in your official records.

275 – 9. He or she may request a letter of evaluation from someone in the TDY unit.

276 – 1. To define the problem. If you can precisely identify the problem, the next step of deciding what you want to do about it, becomes easier.

276 – 2. So that you can gather the necessary facts to make a reliable decision.

276 – 3. From the workers concerned, from records, and from rules, regulations, and technical orders concerning that type of problem.

276 – 4. To enable you to select the best action to take.

276 – 5. To evaluate the action you have taken. You must know if your solution is working. If it isn't, you should be the first to know it, acknowledge it, and come up with another solution to correct it.

277 – 1. A worker with a problem may need assistance; a problem worker may need firm discipline.

277 – 2. Toward helping the individual recognize exactly what the

problem is and guiding the individual toward personally solving the problem himself or herself.

277 − 3. The techniques of good human relations will help prevent or identify and resolve personal problems in the early stages before they grow into big problems. Some personal problems cannot be resolved through good human relations, though, and must be referred to professional assistance.

277 − 4. Doing so helps the supervisor gather valuable facts.

277 − 5. So that they will ask that supervisor to listen or assist them with personal problems.

278 − 1. A supervisor can counsel the individual.

278 − 2. Exactly what is expected at all times.

278 − 3. The individual may be referred to the commander for more severe corrective measures.

278 − 4. Verbal reprimands, written reprimands, Article 15, and recommendation of a court-martial.

278 − 5. Court-martial.

279 − 1. To prevent overpopulating a shop for the size of the normal workload.

279 − 2. The need to the mission.

279 − 3. Programs and Mobility, and Production Analysis.

280 − 1. It tells the interested supervisor where workers are spending their time.

280 − 2. AFTO Form 95, Significant Historical Data.

280 − 3. The analysis section.

281 − 1. To insure mission completion and personnel safety.

281 − 2. Timely, correct, and safe completion.

281 − 3. Lax supervision implies an uncaring attitude which produces carelessness and poor work which, in turn, produces incomplete or aborted missions.

281 − 4. Mistrust, which causes a decline in workers' initiative and support.

282 − 1. The mission of the command and the mission of the base or unit.

282 − 2. The squadron mobility activity.

282 − 3. A shop supervisor identifies personnel and equipment needed to support mobility activity, informs the squadron mobility activity of the section's ability to support the plan, maintains mobility equipment, trains mobility personnel, and participates in evaluating test exercises.

282 − 4. Make sure that the item is modified or replaced so that the equipment in the kit can be used if needed.

CHAPTER 5

283 − 1. Lateral, longitudinal, and vertical axis.

283 − 2. Elevators.

283 − 3. The aircraft will climb—nose up.

283 − 4. Left movement of the control stick.

283 − 5. The left aileron will move up, and the right aileron will move down.

283 − 6. The right rudder pedal.

283 − 7. Ailerons and elevators.

284 − 1. Lift, thrust, gravity, and drag.

284 − 2. Thrust.

284 − 3. The weight will decrease and the effects of gravity will be less.

284 − 4. Induced, profile, and parasite.

285 − 1. If a body is disturbed at rest and then continues to move away from its initial position.

285 − 2. Static and dynamic stability.

285 − 3. Neutral static stability.

285 − 4. A positive form.

286 − 1. The aircraft angle of attack must be increased to a nose-high attitude.

286 − 2. The angle of attack at 25,000 feet would have to be higher (nose up) because the air density is much less at high altitudes.

286 − 3. The angle of attack must be decreased.

287 − 1. The angle of attack remains the same.

287 − 2. The thrust must be increased to overcome the component of weight acting in the same direction and parallel to the total drag of the aircraft so that the thrust is equal to the total drag plus the added component of weight.

287 − 3. During a descent, the airspeed increases due to the component of weight acting forward along the flight path.

287 − 4. Lift acts inward toward the center of the turn as well as upward.

287 − 5. Vertical component is opposite weight, and horizontal component is toward the center of the turn.

287 − 6. During a turn, the lift is divided into two components, reducing the amount of lift supporting the weight, thus causing a loss of altitude. Correction is made by increasing the angle of attack.

287 − 7. Increasing bank angle.

287 − 8. In the direction of the bank (the high wing).

287 − 9. The rate of turn is not great enough for the bank angle.

287 − 10. The rate of turn is too great for the amount of bank.

287 − 11. Good coordination in the use of the ailerons and the rudder to obtain the correct bank angle for the rate of the turn.

288 − 1. Fighters, bombers, and cargo aircraft.

288 − 2. Fighters, characteristically, are single- or dual-seat aircraft with either one or two engines.

288 − 3. Cargo.

288 − 4. Swept back.

289 − 1. Fuselage, wings, and empennage.

289 − 2.
(1) c.
(2) a.
(3) b.

290 − 1. It provides maintenance personnel with a three-dimensional location system to find parts and components on the aircraft.

290 − 2. Body (fuselage) station numbers, body buttock lines, wing station lines, and water line references.

290 − 3. Inches.

291 − 4. On the right wing 88.36 inches from the longitudinal centerline of the aircraft.

290 − 5. Water line 0.00 may be the lowest part of the fuselage or an imaginary line running through both wing tips. Check the TO for your type of aircraft.

290 − 6. Wing stations (wing buttock lines).

291 − 1. To fasten together parts of a mechanism or structure.

291 − 2. AN (Air Force–Navy Standard), NAS (National Aircraft Standard), internal wrenching, and close tolerance bolts.

291 − 3. (1) g.
(2) e.
(3) g.
(4) ~~f~~ b.
(5) c.
(6) a.

292 − 1. Self-locking or nonself-locking.

292 − 2. Color of material and construction (style, size, etc.).

292 − 3. The threads of a nut mate those of the bolt.

292 − 4. Non-self-locking nuts.

293 − 1. To protect the surface of the material upon which a nut or bolt head would bear.

293 − 2. As spacers.

293 − 3. The spring action of a lock washer provides friction to prevent loosening of a nut or bolt.

294 − 1. They are intended to be threaded into holes or nuts which have matching threads.

294 − 2. Hardened steel.

294 − 3. Drive screws.

294 − 4. Where head projections are not objectionable.

294 − 5. Countersunk screws.

295 − 1. MIL–H–5593, low pressure hose.

295 − 2. With yellow specification numbers, size number, date of manufacture, and Federal Supply Code Number.

295 − 3. For fuel and oil in engine compartments.

295 − 4. Aeroquip 601 and stratoflex 156 series hose. It is used for fuel, oil, and hydraulic fluid where flexibility, light weight, and ability to withstand high operating temperatures with maximum fire resistance are prime considerations.

295 – 5. The size of tubing the hose is used with.
296 – 6. Hose that is over 4 years old, or showing signs of weather checking, cracks, or separation of plies will not be used on aircraft or accessories.
295 – 7. Twisting reduces the life of the hose by producing flat spots, collapsing, separation of plies, etc., and it may cause the fittings to loosen.
295 – 8. Separation of the cover or braid from the inner tube or wire braid. Also, look for cracks, hardening, lack of flexibility, evidence of rubbing, kinking, distortion, bulging, collapse, or sharp bending.
295 – 9. For general purpose lines carrying low and medium pressures.
295 – 10. Stainless steel tubing.
295 – 11. Kinks, nicks, cuts, scratches, and other evidence of chaffing.

296 – 1. To permit the use of seals (O-rings) to make a connection to a component airtight.
296 – 2. Blue.
296 – 3. In addition to the basic part number, the complete part number of a fitting identifies the material the fitting is made of and its size.
296 – 4. For high-pressure systems that are subject to severe vibrations and fluctuating pressures.
296 – 5. Standard machine threads.
296 – 6. AN flared fittings.

297 – 1. Never.
297 – 2. Because of prior nonuse of an antiseize compound or because two dissimilar metals were joined.
297 – 3. The threads are probably stripped.
297 – 4. It was probably extruded or cut during installation.

298 – 1. Every tool is designed for a specific purpose. Substituting one tool for another will prevent a job from being done properly and safely.
298 – 2. It causes slippery hands which, in turn, can cause bruised knuckles.
298 – 3. You should clean your work area thoroughly. This helps you account for your tools and eliminates FOD hazards.
298 – 4. Accident reports are useful in determining if a tool or tool design is defective and needs to be changed.

299 – 1. A standard screwdriver has a straight flat blade; whereas the blades of a Phillips screwdriver are crossed and pointed.
299 – 2. Once the blade of a ratchet screwdriver is inserted into the screw slot, the screw can be turned completely in or out by using the ratchet action without removing and reinserting the driver blade for each turn of the screw.
299 – 3. An offset screwdriver.

300 – 1. a. Needle nose pliers.
  b. Vise grip pliers.
  c. Diagonal pliers.
300 – 2. a. Using them for heavy gripping.
  b. Using excessive force.
  c. Using them on bolt heads or nuts.
  d. Any use other than on electrical connectors and conduits. Careless use results in slipping and thus scoring and damaging the connector or conduit.

301 – 1. a. A box-end wrench.
  b. A deep-well socket or box-end wrench.
  c. An allen wrench.
  d. A torque wrench.
  e. A box-end wrench.
301 – 2. a. Select the proper size since incorrect size wrenches tend to slip. Always pull on wrenches; do not push.
  b. Do not try to use an open-end wrench to break loose highly-torqued difficult nuts or bolts.
  c. Adjustable wrenches should fit snugly, and the strain should be placed on the fixed jaw.
  d. Don't pull beyond the click of a torque wrench, and don't use it if the calibration is overdue.
301 – 3. The flexible beam and breakaway or automatic release.
301 – 4. The automatic release type.
301 – 5. The due date, written as the Julian Date or as the day, month, and year will be attached to the wrench in some manner.
301 – 6. By subtracting 60 days from the "date due" which is indicated on a label on the wrench.
301 – 7. Its accuracy must be verified prior to further use.
301 – 8. Turn the handle counterclockwise past the desired setting, then turn the handle clockwise until the desired setting is reached. The desired torque setting should always be approached from the lower end of the scale.
301 – 9. 60 days.
301 – 10. To its lowest setting, to prevent the spring from becoming distorted.
301 – 11. a. 199 inch-pounds.
  b. 50 inch-pounds.
  c. 360 inch-pounds.
  d. 200 inch-pounds.
  e. 80 inch-pounds.

302 – 1. Hard-faced, soft-faced, and mallets.
302 – 2. The ball shaped end of a ball-peen hammer is used to peen (expand or stretch) metal; for example, expanding the end of a rivet. The flat-faced end is used for tapping punches and chisels or other rough work.
302 – 3. On soft materials to prevent damage to the material.
302 – 4. Hammer accidents usually result from loose or cracked handles, improper striking, or damaged or dirty hammer faces. Sweaty palms and greasy handles also contribute to accidents involving hammers.

303 – 1. Mill files are used primarily for precision work where a smooth finish is desired. Pillar files are used for filing slots and keyways and for filing work in close quarters. Swiss pattern files are used for precision work on instruments and delicate mechanisms.
303 – 2. Single cut.
303 – 3. Start the stroke with light pressure near the point of the file, increasing pressure as the file is pushed across the surface and making each stroke slow and steady.
303 – 4. Files are cleaned by drawing a file card and brush back and forth across the file parallel to the cutting teeth. When stored, they should be kept separated in a dry place.

304 – 1. Loosening pins or knocking out rivets after the heads have been drilled or sheared off.
304 – 2. To complete jobs begun by starting punches; to completely remove pins from their holes.
304 – 3. The pin could spread and freeze in the hole.
304 – 4. Mushroomed heads on punches may permit pieces of steel to break off. Those flying pieces of steel can cause serious personal injury, especially to the eyes.
304 – 5. Carbon steel drills are designed for low-speed drilling and light work. Heavy work and high speeds cause them to overheat, lose their hardness, and become dull.
304 – 6. Always use a center punch to start your holes to prevent the drill from wandering. Start the electric drill before placing the point of the twist drill in the punch mark. Maintain a steady pressure until the point of the drill begins to break through; then ease off on the pressure, proceeding gently so that the bit will not bind.
304 – 7. When drilling copper, lubricate the bit with oil; for tool steel, also use oil; for brass, no lubricant is required; and for soft steel, use oil or soda water.

1986-631-028/40450 AUGAFS,AL(863805)200

S T O P - 1. MATCH ANSWER SHEET TO THIS EXERCISE NUMBER.
2. USE NUMBER 2 PENCIL ONLY.

EXTENSION COURSE INSTITUTE
VOLUME REVIEW EXERCISE

32551 02 24

SPECIALTY ADMINISTRATION AND AIRCRAFT FAMILIARIZATION

Carefully read the following:

DO's:

1. Check the "course," "volume," and "form" numbers from the answer sheet address tab against the "VRE answer sheet identification number" in the righthand column of the shipping list. If numbers do not match, return the answer sheet and the shipping list to ECI immediately with a note of explanation.
2. Note that item numbers on answer sheet are sequential in each column.
3. Use a medium sharp #2 black lead pencil for marking answer sheet .
4. Write the correct answer in the margin at the left of the item. (When you review for the course examination, you can cover your answers with a strip of paper and then check your review answers against your original choices.) After you are sure of your answers, transfer them to the answer sheet. If you have to change an answer on the answer sheet, be sure that the erasure is complete. Use a clean eraser. But try to avoid any erasure on the answer sheet if at all possible.
5. Take action to return entire answer sheet to ECI.
6. Keep Volume Review Exercise booklet for review and reference.
7. If mandatorily enrolled student, process questions or comments through your unit trainer or OJT supervisor. If voluntarily enrolled student, send questions or comments to ECI on ECI Form 17.

DON'Ts:

1. Don't use answer sheets other than one furnished specifically for each review exercise.
2. Don't mark on the answer sheet except to fill in marking blocks. Double marks or excessive markings which overflow marking blocks will register as errors.
3. Don't fold, spindle, staple, tape, or mutilate the answer sheet.
4. Don't use ink or any marking other than a #2 black lead pencil.

NOTE: **NUMBERED LEARNING OBJECTIVE REFERENCES ARE USED ON THE VOLUME REVIEW EXERCISE.** In parenthesis after each item number on the VRE is the Learning Objective Number where the answer to that item can be located. When answering the items on the VRE, refer to the Learning Objectives indicated by these Numbers. The VRE results will be sent to you on a postcard which will list the actual VRE items you missed. Go to the VRE booklet and locate the Learning Objective Numbers for the items missed. Go to the text and carefully review the areas covered by these references. Review the entire VRE again before you take the closed-book Course Examination.

MULTIPLE CHOICE

Note to Student: Consider all choices carefully and select the best answer to each question.

1. (200) The responsibility for the care and safeguarding of property is charged to the

a. commander.
b. shop supervisor.
c. branch supervisor.
d. individual having possession.

2. (201) In case of the loss, damage, or destruction of government property, what does command responsibility do for officers?

a. Protects them from pecuniary liability.
b. Allows them to assign pecuniary liability.
c. Makes them pecuniarily liable.
d. Makes them solely responsible for assigned property.

3. (202) When must you assume supervisory responsibility over equipment and supplies?

a. When directed by your squadron commander.
b. When directed by your shop supervisor.
c. When supervising other personnel working with equipment.
d. When possessing Air Force equipment.

4. (203) What type responsibility should you assume for property that has been found?

a. Command.
b. Pecuniary.
c. Custodial.
d. Supervisory.

5. (204) What determines the cost to an individual for property lost, damaged, or destroyed?

a. The condition of the property.
b. The original cost to the Air Force.
c. Replacement cost to the Air Force.
d. Value to the Air Force.

6. (205) When property is turned-in, what must occur for a person to be relieved of the responsibility for the property?

a. The commander must approve the turn-in.
b. The turn-in must be properly documented.
c. The property has to be cleaned.
d. The property has to be made serviceable.

7. (206) What form is used to settle a monetary obligation for lost, damaged or destroyed government property, when pecuniary liability is admitted but the airman is unable to pay cash?

a. DD Form 1131, Cash Collection Voucher.
b. DD Form 362, Statement of Charges.
c. DD Form 2090, GPLD Survey Certificate.
d. DD Form 114, Military Pay Order.

8. (207) When must a report of survey be prepared?

a. When person admits liability or the amount involved is over $350.00.
b. When a person does not admit liability or if the amount involved is over $250.00.
c. When a person admits liability and the amount involved is less than $250.00.
d. When a person admits liability and the amount involved is less than $350.00.

9. (208) Who determines the exact quantities of test equipment your shop is authorized to have?

a. The allowance and authorization section of base supply and the major command.
b. The allowance and authorization section of base supply and your shop chief.
c. The major command and your squadron commander.
d. The major command, your squadron commander and your shop chief.

10. (208) The Bench Stock Support Unit resupplies authorized stocks of which low cost, frequently used items?

a. DIFM assets.
b. Office supplies.
c. Cleaning supplies.
d. Expendable items.

11. (209) Which TA category includes aircraft maintenance, Navigation/Flight Control System, and instrument systems maintenance?

a. Systems support.
b. Facilities support.
c. Mission support.
d. Equipment support.

12. (210) The basis of issue for a piece of equipment is determined by what?

a. Number of people assigned.
b. Skills of personnel assigned.
c. Number of aircraft assigned.
d. Type of aircraft assigned.

13. (211) How should you obtain authorization for equipment when you need more than the Table of Allowance authorizes you to have?

a. Use the authorization in a different TA.
b. Submit justification for the increase.
c. Obtain the approval of your squadron commander.
d. You cannot have more than the TA authorizes.

14. (212) Which part of National Stock Number (NSN) 4920-00-933-1410 is the Federal Supply Classification Code?

a. 4920.
b. 1410.
c. 933.
d. 00.

15. (213) Which microfiche listing is arranged in numerical sequence by the national item identification number?

a. C-RL-1.
b. C-RL-2.
c. ML-AF.
d. IL-AF.

16. (214) When the supply computer is not operational,

a. supply requests cannot be filled from warehouse locations.
b. all parts must be issued through the reparable processing center.
c. requests are filled and the computer is updated later using POST-POST documents.
d. requests must be handcarried to supply and items exchanged on a one-for-one basis.

17. (215) One disadvantage of bench stocks is

a. items must be paid for before use.
b. bins may be empty when the items are needed.
c. unauthorized people can use the items.
d. substitute items are not available.

18. (216) What is used on a bench stock label to identify cure-dated items?

a. Inspection due date.
b. Shelf-life code.
c. Controlled item code.
d. Security code.

19. (217) What is the purpose of the activity code used in the supply document number?

a. It identifies the major command which will be charged for the item.
b. It identifies the method or section of base supply used to process the request.
c. It identifies the shop or office requesting the item.
d. It tells the computer which mode it must use to process the equipment.

20. (218) What type of information goes in the first three blocks (TRIC) of the AF Form 2005?

a. A code which identifies the type of transaction being conducted with supply.
b. A code which identifies the urgency in which the item is needed.
c. A code which tells supply where to deliver the item requested.
d. A code which determines which report the request will be logged on.

21. (219) Supply requests made by radio or telephone

a. will be recorded on the AF Form 1348-1 in order to verify the daily document register.
b. will be recorded on the AF Form 2005 in order to verify the due-out validation listing.
c. will be recorded on the AF Form 2411 in order to verify the priority monitor report.
d. will be recorded on the AF Form 2413 in order to verify the daily document register.

22. (220) All requests for test equipment must be approved by whom?

a. The equipment custodian.
b. The shop chief.
c. The organization commander.
d. The chief of supply.

23. (221) If you must send a part back to a depot facility for repair, which condition tag must accompany it?

a. DD Form 1574 (yellow).
b. DD Form 1575 (brown).
c. DD Form 1577 (red).
d. DD Form 1577-2 (green).

24. (221) Reparable material which is of no further use to the Air Force will have which condition tag attached when it is turned in to base supply?

a. DD Form 1574 (yellow).
b. DD Form 1575 (brown).
c. DD Form 1577 (red).
d. DD Form 1577-2 (green).

25. (222) When seen on the daily document register, what does DOR mean?

a. Payment for the item is due on receipt.
b. The item was issued after being back ordered.
c. The item is being shipped to you from depot.
d. Your order will be processed when the computer is operational.

26. (223) Which supply listing is provided daily so you can monitor the status of your requests for urgently needed items?

a. Daily document register.
b. Priority monitor report.
c. DIFM Listing.
d. Due-OUT Validation Listing.

27. (224) What are the three phases of the Maintenance Data Collection System?

a. Collection, verification, and storage of data.
b. Collection, coding, and processing of data.
c. Collection, storage, and retrieval of data.
d. Collection, storage, and evaluation of data.

28. (224) Which one of the following is an intended on-base use of MDC data?

a. Validate or adjust calibration intervals.
b. Establish priorities for product improvement actions.
c. Compile maintenance man-hours per flying hour data.
d. Summarizing productive labor and indirect labor-hour expenditures.

29. (225) Who is primarily responsible to ensure that MDC forms are filled out correctly before they are forwarded for processing into daily and monthly reports?

a. Keypunch operator.
b. Analysis chief.
c. Workcenter supervisor.
d. Quality control chief.

30. (226) Which MDC report must be provided to all users of the MDC system regardless of the accuracy of the data contained on it?

a. MDC Daily Transaction Listing.
b. MDC Daily Transaction Error Listing.
c. MDC Monthly Transaction Listing.
d. MDC Work Summary.

31. (227) What is a circle graph normally used to show?

a. The increase of something over a given period of time.
b. The relationship between two quantities.
c. Relation of parts to the whole.
d. A cycle of recurring events.

32. (228) What entry on the AFTO Form 350 relates a shop repair action on a component to a specific job on an aircraft?

a. Aircraft serial number.
b. Standard reporting designator.
c. Job control number.
d. Work unit code.

33. (229) What is the purpose of the standard reporting designator (SRD)?

a. To permit data processing for individual serially numbered components.
b. To permit data processing for different groupings of equipment.
c. To permit data processing and retrieval for personnel data.
d. To permit data processing and assignment of maintenance personnel and equipment.

34. (230) The AFTO Form 349 is used to document which categories of MDC data?

a. On-equipment, off-equipment, and direct labor.
b. On-equipment, off-equipment, and indirect labor.
c. Direct, indirect, and routine labor.
d. Maintenance, nonmaintenance, and training efforts.

35. (231) Portions of what codes and numbers are used to make up an aircraft or equipment ID number?

a. Command activity identification code, workcenter code, and MDS code.
b. SRD code, MDS code, and job control number.
c. MDS code, workcenter code, and serial number.
d. Workcenter code, SRD code, and serial number.

36. (232) Which technical order series provides the guidance for documenting all maintenance actions?

a. 0-1-33.
b. 0-4-6-1.
c. 00-20-2.
d. 00-25-234.

37. (233) Under what conditions are entries made in blocks 4 (MDS) and 5 (SRD) of the AFTO Form 349?

a. When the appropriate codes can be determined.
b. When a locally assigned ID number is available.
c. For transient aircraft or equipment which does not have an assigned ID number.
d. When work is performed in the shop.

38. (234) Who makes most entries required on Part II of the AFTO Form 350?

a. The same person who fills out Part I.
b. The person who repairs the item.
c. Production Control/Reparable Processing Center personnel.
d. Maintenance Control/Material Control personnel.

39. (235) What roles does production control play with respect to repair cycle assets?

a. PC is the central point for controlling, scheduling, and routing repair cycle assets.
b. PC is the central point for insuring that repair cycle assets are economically repaired.
c. PC is responsible for making sure sufficient personnel are available to repair assets.
d. PC assigns shops and individual specialists to repair specific assets.

40. (236) Which of the following ERRC codes is not normally used for repair cycle assets?

a. XB3.
b. XF3.
c. XD2.
d. XD3.

41. (237) Noncritical DIFM assets will be returned to supply in how many days?

a. 3.
b. 5.
c. 10.
d. 14.

42. (238) When bits and pieces are requested to repair DIFM asset, what further action is required by the requesting shop?

a. No further action is required until the bits and pieces are received.
b. Verification of the urgency of need (UJC) by QC must be obtained.
c. The Production Control scheduler must be given a new estimated repair completion time.
d. Maintenance Control must be notified that the specialist is now available for dispatch.

43. (239) Under which of the following conditions would a Category II Material Deficiency Report be submitted?

a. When a condition exists which, if not corrected, would result in a serious injury to personnel.
b. When a condition exists which, if not corrected, would seriously affect the defense of the United States government.
c. When a material deficiency exists, even though it was caused by improper handling of the equipment.
d. When a material deficiency exists and is attributable to nonconformance with applicable specifications, drawings, standards, and errors in workmanship.

44. (240) Who must review all MDRs prior to submission to insure that they are reported under the correct method and are routed correctly?

a. The immediate supervisor.
b. The shop supervisor.
c. PC/RPC.
d. Quality Control.

45. (241) How long may MDR exhibits be held pending disposition instructions?

a. 15 days.
b. 20 days.
c. 25 days.
d. 30 days.

46. (242) Which form of the AFTO Form 781 series contains basic information to aid in making entries on the AFTO Form 781 series?

a. 781A.
b. 781F.
c. 781G.
d. 781K.

47. (243) The use of which status symbol indicates that a system may be operable or inoperable, good or bad, safe or unsafe?

a. Red X.
b. Red dash.
c. Red diagonal.
d. Circles red X.

48. (245) What two Air Force regulations outline maintenance management procedures?

a. AFR 661 and AFR 671.
b. AFR 66-1 and AFR 66-5.
c. AFR 60-16 and AFR 66-5.
d. AFR 66-33 and AFR 65-110.

49. (246) In addition to correcting the discrepancies described in Quality Assurance Reports, what else should be done?

a. Nothing; correcting known deficiencies is all that is necessary.
b. Report all actions taken to correct each deficiency.
c. Inform other personnel subject to similar discrepancies, of your corrective actions.
d. Identify and eliminate the cause of each deficiency.

50. (247) What is required of maintenance to generate one sortie?

a. Enough time, people and equipment to prepare one aircraft for flight.
b. Enough crew members to fly one group of airplanes to a specific destination.
c. Enough AFTO Forms 349 to produce a valid Daily Transaction Listing.
d. Enough telephone requests for parts for supply to deliver them to the shop.

51. (248) What must the squadron commander demand of you while you are performing your job?

a. Expedient maintenance actions with strict adherence to safety requirements.
b. Professional, quality maintenance with strict adherence to technical orders.
c. Initiative and imagination to produce operational systems under all circumstances.
d. Dedication to the Air Force and devotion to duty.

52. (249) What is the purpose of organization/functional charts?

a. To clarify where individuals fit into the unit.
b. To outline different shop responsibilities.
c. To reflect the flow of MDC forms and reports.
d. To establish office symbols and supply delivery points.

53. (250) The Deputy Chief of Maintenance controls, schedules and monitors operations within the maintenance complex by use of

a. Job Control.
b. AFM 66-1.
c. Plans and scheduling.
d. staff agencies.

54. (251) The overall objective of Production Analysis is to

a. correct problem areas that are apparent in the maintenance organization.
b. make sure that all personnel in the maintenance organization are doing their job.
c. correct any deviations from acceptable standards by a maintenance squadron.
d. improve maintenance through use of maintenance data evaluation.

55. (252) Which of the following activities assumes weight and balance, functional check flight and deficiency reporting responsibilities?

a. Quality Control.
b. Plans and Scheduling.
c. Management Support.
d. Maintenance Control.

56. (253) To which section would you go if you wanted to know if a TCTO had been performed on a specific aircraft?

a. The unit historian.
b. Quality Control.
c. Plans, Scheduling and Documentation.
d. Avionics Production Analysis.

57. (254) The alert force is a branch of which squadron under AFR 66-1?

a. AMS.
b. FMS.
c. OMS.
d. AGS.

58. (255) Under POMO, in-shop maintenance of avionics equipment is performed by which squadron?

a. AMS.
b. AGS.
c. CRS.
d. EMS.

59. (256) Prior to being utilized in the CUT program, the instrument worker must

a. be qualified at task assist training duties.
b. have acquired a 5-skill level.
c. have achieved technician status.
d. be promoted to E-4, SrA.

60. (257) If you are unable to fix an instrument problem on an aircraft and your shop chief determines that the job is beyond your shop's capabilities, who is contacted for assistance?

a. The branch chief.
b. The squadron commander.
c. Quality Control.
d. Depot.

61. (258) If you put all the inspection requirements for a particular aircraft together and divide them into small inspections of equal length, what inspection concept are you operating under?

a. Phase.
b. Isochronal.
c. Home station check.
d. Periodic.

62. (259) Most aircraft inspections are performed in what phases?

a. Look phase and fix phase.
b. Preinspection, inspection and post inspection.
c. Preinspection, look phase, fix phase, and post inspection.
d. Preinspection, inspection, repair phase, and operational checks.

63. (260) Which of the following are traits of a leader?

a. Has initiative, is decisive, is interested in people, and is patient and controlled.
b. Is understanding of failures, is friendly, is arrogant, and is insensitive to human needs.
c. Is willing to complete assignments, takes pride in personal achievements, works hard for recognition.
d. Drives people to get the job done, is obviously the boss, doesn't tolerate mistakes, and demands compliance.

64. (261) What areas must a supervisor understand to be effective?

a. Organizational structure, administrative procedures, and influencing people.
b. Influencing people, evaluation procedures, and logical reasoning.
c. Responsibilities, employee relations, and production.
d. Production, race relations, and safety procedures.

65. (261) Recognition, opportunity, security, and belonging are best described as what?

a. Luxuries not needed in the military.
b. Basic needs of people.
c. Differences in people.
d. Benefits of Air Force service.

66. (262) What do the differences in people mean to an Air Force supervisor?

a. Nothing, as military standards apply to all.
b. Care must be exercised to prevent equal opportunity violations.
c. They determine assignments, growth potential and worker actions.
d. They must be made to conform to Air Force requirements.

67. (263) When changes in the shop are required, how can the supervisor get their support and approval on the changes?

a. By personally contacting each individual.
b. By posting written notices and bulletins.
c. By having informal meetings and discussions.
d. By encouraging workers' interest and participation.

68. (264) The slogan of the most effective supervisor may very well be which of the following?

a. Keep the workers happy.
b. Practice good human relations.
c. Produce, or else.
d. The mission comes first.

69. (264) What are the best supervisory techniques for accomplishing the mission of aircraft maintenance.

a. Use production centered techniques.
b. Use worker centered techniques.
c. Use the authority of the supervisory position to gain production.
d. Practice good human relations.

70. (265) Which function of management requires the ability to visualize the complete process of completing a job, including the finished product?

a. Planning.
b. Organizing.
c. Directing.
d. Controlling.

71. (266) Unity of command, span of control, functional grouping, and delegation of authority are functions of what?

a. Management.
b. Planning.
c. Organizing.
d. Directing.

72. (266) What factors limit a supervisor's span of control?

a. Number of people, distance from workers, rank structure, and position.
b. Position, distance from workers, attitudes, and authority of the supervisor.
c. Organization of the unit, duties to be done, position and authority of the supervisor.
d. Distance from workers, number of workers, nature of work, and skill of workers.

73. (267) You receive a work request to complete a very complicated inspection which has low priority. Of your two equally qualified 5-level specialists Ed and Pete, Ed has experience with this type of inspection, but Pete does not. To whom should you assign the job, and why?

a. Pete, because he needs the experience, and the job has a low priority.
b. Ed, because Pete is not experienced.
c. Ed, because he is experienced.
d. Pete, because he is a qualified 5-level.

74. (267) What aids are used to monitor work distribution, job assignment, job progress, and personnel locations?

a. Specialist dispatch board or two-way radios.
b. Specialist dispatch control log and shift supervisors.
c. Shift supervisors and two-way radios.
d. Specialist dispatch board or control log.

75. (268) What type of directions should you use for workers you know well?

a. Simple requests.
b. Orders.
c. No-nonsense instructions.
d. Various types.

76. (269) Why should complicated, detailed directions be given orally?

a. Nothing is overlooked and everything is explained thoroughly.
b. Reason can be given along with explanations.
c. Oral directions provide an opportunity for questions.
d. They should be written, not given orally.

77. (270) A careless attitude displayed by a supervisor

a. causes a loss of respect from the workers.
b. doesn't normally affect good workers.
c. is reflected in the workers' attitudes.
d. should be overlooked because supervisors are human too.

78. (271) The management function of coordination is

a. a supervisory responsibility.
b. a command responsibility.
c. a natural function of directing.
d. everyones' job.

79. (271) Coordination in aircraft maintenance

a. is the job of maintenance control.
b. requires good communications.
c. is very difficult to achieve.
d. is controlled by the DCM.

80. (272) In aircraft maintenance, what must be the basis of any system used to control the quality of maintenance?

a. Experienced quality control inspectors.
b. Active maintenance supervisors.
c. Realistic standards of performance.
d. Knowledgeable maintenance specialists.

81. (273) What type of performance standards stimulate people to work?

a. Precise operating details.
b. Reasonably attainable standards.
c. Demanding standards.
d. Easily reached levels of performance.

82. (274) What is the danger to the shop in giving an employee a higher than deserved rating on an APR?

a. The incentive of other personnel may be destroyed.
b. The endorsing official may disagree.
c. The supervisor may lose the respect of his/her boss.
d. The employee may be sent to another base.

83. (274) What human characteristic is most likely to affect the validity of an APR?

a. The rater will find that it is easier to rate low than it is to rate high.
b. The rater will have a low opinion of young people.
c. The rater will know too much about the person.
d. The rater will remember unusual performance longer than typical performance.

84. (275) What is the basis of the overall rating given on an APR?

a. The rater's comments in section V.
b. All other areas not covered in section III.
c. The combined evaluations made in section III.
d. The duties listed in section II.

85. (276) Identyfying the trouble, establishing objectives, gathering facts, weighing and deciding, taking action, and evaluating action are six steps in

a. training.
b. planning.
c. problem solving.
d. maintenance management.

86. (277) What is frequently an effective way to help a person understand exactly what the solution to his or her problem is?

a. Offering your opinion and advice.
b. Discussing the consequences of the problem.
c. Discussing the solution to the problem.
d. Discussing the problem.

87. (278) What is usually the last resort for substandard performance?

a. An official written reprimand.
b. Confinement under Article 15.
c. A heavy fine and demotion under Article 15.
d. A recommendation for court-martial.

88. (279) What must be used to justify requests for more people or equipment?

a. The number and type of aircraft assigned.
b. The skill level and experience of personnel.
c. The current amount of work to be done.
d. The normal need for mission accomplishment.

89. (280) How can reviewing the AFTO Forms 95, Aircraft Histories, help a specialist or technician fix an instrument system?

a. It cannot help.
b. It shows what other shops have had problems with.
c. It shows what was done to that system in the past.
d. It shows who "could not duplicate" the problem before.

90. (281) Why must personnel be supervised?

a. To encourage personnel to work harder and work together.
b. To insure mission completion and personnel safety.
c. To prevent them from feeling rejected and unappreciated.
d. To insure that the Air Force gets the labor it pays for.

91. (282) Identifying the personnel and equipment needed to support mobility requirements is primarily whose responsibility?

a. The shop chief's.
b. The squadron mobility activity's.
c. The squadron commander's.
d. The Deputy Commander for Maintenance.

92. (283) Which flight control surface guides the movement of the aircraft about the vertical axis?

a. Rudder.
b. Aileron.
c. Elevator.
d. Wing flap.

93. (284) The component of the total air forces which is set up by friction and turbulence as air passes over an aircraft is

a. gravity.
b. thrust.
c. lift.
d. drag.

94. (285) If a body at rest is disturbed and tends to return to its original position, the body has

a. neutral static stability.
b. positive static stability.
c. negative static stability.
d. neutral dynamic stability.

95. (286) Angle of attack must be increased if

a. weight and altitude decrease.
b. air density and load increase.
c. airspeed decreases or weight decreases.
d. altitude increases or airspeed decreases.

96. (287) During a turn, lift forces act

a. downward and outward.
b. downward and upward.
c. upward and outward.
d. inward and upward.

97. (288) What type of aircraft is designed specifically to seek out and destroy other aircraft?

a. Cargo.
b. Bomber.
c. Transport.
d. Fighter.

98. (289) Identify the main structural unit of an aircraft.

a. Under carriage.
b. Empennage.
c. Fuselage.
d. Wings.

99. (290) The distances from below the lowest part of the fuselage upward is called

a. water lines.
b. body station numbers.
c. wing station numbers.
d. body buttock lines.

100. (291) The size of a bolt is generally stated in terms of

a. the type of head and threads per inch.
b. the length, diameter and threads per inch.
c. the diameter and threads per inch.
d. either the slotted or recessed head.

101. (292) For maximum locking effect, how many bolt threads should extend through a self-locking nut?

a. 1.
b. 2.
c. 3.
d. 4.

102. (293) How do lockwashers prevent loosening of nuts or bolts?

a. They gouge the surface of the material.
b. They provide friction by their spring action.
c. The uneven ends mate slots in the nut or bolt.
d. The tabs provide safety wire holes.

103. (294) Which type of slotted screws are made of hardened steel so they can tap their own threads?

a. Machine screws.
b. Drive screws.
c. Sheet metal screws.
d. Filister head screws.

104. (295) How is hose size determined?

a. By inside diameter.
b. By outside diameter.
c. By the size of the fittings used on it.
d. By the size of the tubing used with it.

105. (296) What characteristics of a fitting are reflected in its part number?

a. basic design.
b. basic design and size.
c. basic design, size, and construction material.
d. basic design, size, construction material, and type of threads.

106. (296) Overtightening a B nut on a flared fitting may

a. result in a permanently sealed joint.
b. squeeze out all the antiseize compound from the threads.
c. necessitate the use of a thread compound for removal.
d. badly damage or completely cut off the tube flare.

107. (297) Which type of threads are used to draw and hold connections together rather than to form a seal?

a. Pipe threads.
b. Machine threads.
c. Adapter threads.
d. Universal threads.

108. (298) What is the best rule to follow when using hand tools?

a. Use only authorized maintenance techniques, tools and materials.
b. Keep your work area and tools neat and clean at all times.
c. Select the right tool for the job.
d. Develop safe work habits and use common sense.

109. (299) Which of the following is a proper use of a screwdriver?

a. Using a Reed and Prince screwdriver to remove a Phillips head screw.
b. Using a wrench on a thick square shanked screwdriver to apply more turning pressure.
c. Holding a small component in one hand and using a Reed and Prince screwdriver to remove a Reed and Prince screw from it.
d. Using a large flat bladed screwdriver to pry open a wooden box on which the top has been nailed.

110. (300) If wire twisting pliers are not available, which other type of pliers is most appropriate for twisting safety wire in confined areas?

a. Half-round nose pliers.
b. Needle-nose pliers.
c. Duck-bill pliers.
d. Diagonal pliers.

111. (301) An adjustable jaw wrench is properly used when

a. the handle is pushed away from you.
b. the handle is pulled away from the jaw.
c. the force is applied to the stationary jaw.
d. a pipe or extension is added to gain leverage.

112. (301) If you have a component that needs to be torqued to 1800 inch-pounds, but have a torque wrench that measures only foot-pounds, what should you do?

a. Divide 12 into 1800.
b. Multiply 12 times 1800.
c. Divide 1800 into 12.
d. Subtract 12 from 1800.

113. (302) Which of the following hammers would you use to avoid metal damage?

a. A tack hammer.
b. A ball peen hammer.
c. A common hammer.
d. A plastic hammer.

114. (303) Which type of file is for fine, detailed work?

a. Single-cut.
b. Double-cut.
c. Mill.
d. Pillar.

115. (304) What is the greatest danger in using a punch which has a mushroomed head?

a. Pieces of steel may break off.
b. The hammer may slip off the head.
c. The hammer blow may cause the punch to twist.
d. Hands could be cut on the jagged edges of the mushroomed head.

END OF EXERCISE

MAIL TO: ECI, GUNTER AFS AL 36118-5643

STUDENT REQUEST FOR ASSISTANCE

PRIVACY ACT STATEMENT

AUTHORITY: 10 USC 8012. PRINCIPAL PURPOSE: To provide student assistance as requested by individual students. ROUTINE USES: This form is shipped with ECI course package, and used by the student, as needed, to place an inquiry with ECI. DISCLOSURE: Voluntary. The information requested on this form is needed for expeditious handling of the student's inquiry. Failure to provide all information would result in slower action or inability to provide assistance to the student.

I CORRECTED OR LATEST ENROLLMENT DATA

1. THIS REQUEST CONCERNS COURSE (1-6)	2. TODAY'S DATE	3. ENROLLMENT DATE	4. AUTOVON NUMBER
5. SOCIAL SECURITY NUMBER (7-15) – –	6. GRADE/RANK	7. NAME *(First initial, second initial, last name)* (17) – (18) – (19-32)	
8. ADDRESS *OJT ENROLLEES: Address of unit training office with zip code* *ALL OTHERS: Current mailing address with zip code*	(33-53) (54-75)		
9. NAME OF BASE OR INSTALLATION IF NOT SHOWN ABOVE		10. TEST CONTROL OFFICE ZIP CODE/SHRED (33-38)	

II REQUEST FOR MATERIALS, RECORDS, OR SERVICE

X	*Place an "X" through number in box to left of service requested.*
1	Request address change as indicated in Section I, Block 8.
2	Request Test Control Office change as indicated in Section I, Block 10.
3	Request name change/correction. *(Provide Old or Incorrect data here)*
4	Request Grade/Rank change/correction.
5	Correct SSAN. *(List incorrect SSAN here.)* *(Correct SSAN should be shown in Section I.)*
6	Extend course completion date. *(Justify in "Remarks.")*
7	Request enrollment cancellation. *(Justify in "Remarks.")*
8	Send VRE answer sheets for Vol(s): 1 2 3 4 5 6 7 8 9 10 Originals were: ☐ Not received ☐ Lost ☐ Misused
9	Send course materials. *(Specify in "Remarks.")* ☐ Not received ☐ Lost ☐ Damaged
10	Course exam not yet received. Final VRE submitted for grading on ______________ (date).
11	Results for VRE Vol(s): 1 2 3 4 5 6 7 8 9 10 not yet received. Answer sheet(s) submitted ______________ (date).
12	Results for CE not yet received. Answer sheet submitted to ECI on ______________ (date).
13	Previous inquiry (☐ ECI Fm 17, ☐ ltr, ☐ msg) sent to ECI on ______________ (date).
14	Give instructional assistance as requested on reverse.
15	Other *(Explain fully in "Remarks.")*

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16 G	33	
K	VOL 33-35	SN 36-38
M	33-34	35-40
N	33-35	
P	VOL 33-35	
	TC 36-37	38
	DOE 39-45	
Q	33-34 00	38 1
	MC 39-42	

REMARKS *(Continue on reverse)*

OJT STUDENTS must have their OJT Administrator certify this record.

ALL OTHER STUDENTS may certify their own requests.

I certify that the information on this form is accurate and that this request cannot be answered at this station.

SIGNATURE

ECI FORM DEC 84 17 PREVIOUS EDITION WILL BE USED

BEST COPY AVAILABLE

REQUEST FOR INSTRUCTOR ASSISTANCE

NOTE: Questions or comments relating to the accuracy or currency of subject matter should be forwarded directly to preparing agency. For an immediate response to these questions, call or write the course author directly, using the AUTOVON number or address in the preface of each volume. All other inquiries concerning the course should be forwarded to ECI.

VRE ITEM QUESTIONED:

COURSE NO ____________

VOLUME NO ____________

VRE FORM NO ____________

VRE ITEM NO ____________

ANSWER YOU CHOSE ____________ *(Letter)*

HAS VRE ANSWER SHEET BEEN SUBMITTED FOR GRADING?

☐ YES ☐ NO

REFERENCE

(Textual reference for the answer I chose can be found as shown below.)

IN VOLUME NO ____________

ON PAGE NO ____________

IN ☐ LEFT ☐ RIGHT COLUMN

LINES ________ THROUGH ________

MY QUESTION IS:

REMARKS

ADDITIONAL FORMS 17 available from trainers, OJT and Education Offices, and ECI. Course workbooks have a Form 17 printed on the last page.

ECI FORM 17, DEC 84 *(Reverse)*

32551 03 8201

CDC 32551

AVIONICS INSTRUMENT SYSTEMS SPECIALIST

(AFSC 32551)

Volume 3

Electronic Principles

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THIS PUBLICATION HAS BEEN REVIEWED AND APPROVED BY COMPETENT PERSONNEL OF THE PREPARING COMMAND IN ACCORDANCE WITH CURRENT DIRECTIVES ON DOCTRINE, POLICY, ESSENTIALITY, PROPRIETY, AND QUALITY.

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CHANGE SUPPLEMENT

CDC 32551

AVIONICS INSTRUMENT SYSTEMS SPECIALIST

(AFSC 32551)

Volume 3

IMPORTANT: Make the corrections indicated in this supplement before beginning study of Volume 3. This supplement contains both "pen-and-ink" changes and replacement pages. It is perforated and three-hole-punched so that you can tear out the replacement pages and insert them in your volume. You are not required to post any changes listed in this supplement which correct typographical errors, unless such errors change or otherwise affect the meaning of the material.

This supplement adds 3 hours (1 point) to Volume 3.

Extension Course Institute
Air University

CHANGES FOR THE TEXT:

Pen-and-Ink Changes:

Page-Col	*Subject*	*Line(s)*	*Correction*
iii		10	Between “*corrections*” and “*this,*” insert “*for.*”
		2 fr bot	Change “51 hours (17 points)” to “54 hours (18 points).”
1L		17 fr bot	After “because” insert a comma.
6R		5 fr bot	Delete the comma after “pole.”
8L		25	Change “400” to “4000.”
9L		3	Change “3000” to “300.”
		19 fr bot	Change “$2(1 \times 3)$” to “$2^{(1 \times 3)}$.”
10	Table 1-2	3 fr bot	Above “n” in the Symbol column insert “μ.”
11R		14	Change “$X = 7$” to “$X = 17$.”
12L		10	Change “2X” to “$-2X$.”
12R		4	After “$(S - 6)$” insert “=.”
		13	Change “$S = 1$” to “$S = -1$.”
		12 fr bot	Change “Multiple by (6)” to “Multiply every term by (6).”
		10 fr bot	Change “and” to “Reduce each term to its lowest form.”
		1 fr bot	Change “$7y - \frac{1}{5y}$” to “$\frac{7y - 1}{5y}$.”
14L		16	Change “multiple” to “multiply.”
18L		10 fr bot	Change “ND” to “NO.”
		6, 3, 1 fr bot	Change “R_1” to “R_L.”
18R		1	Change “R_1” to “R_L.”
18R		14	Change “alos” to “also.”
20L		8	Change “any” to “and.”
		3 fr bot	Change “$5d_1$” to “R_1.”
		2 fr bot	Change “R” to “5.”
21L		4	Between “I_{R_2}” and “R_2” insert a “times” sign.
23R		14 fr bot	Change “ratlng” to “rating.”
24L		4 fr bot	Change “training devices” to “systems.”

Page-Col	*Subject*	*Line(s)*	*Correction*
27L		2 fr bot	Change " $\frac{28V}{Ia}$ " to " $\frac{28V}{1a}$."
27R		8	After the long fraction insert "$= \frac{\frac{1}{7}}{56}$."
30R		11	Change the equation to read "$Ra = \frac{R_2R_3}{R_2 + R_3}$."
33L		9	Change "= 50Ω" to "= 50k."
		1 fr bot	Change "= 50Ω" to "= 50kΩ."
34R		18	After "= 2.5" add "mA."
35	Fig. 2-24		Draw in a ground symbol at the end of the line that is connected to the negative battery terminal."
36L		5	Change "I_{R_3}" to "E_{R_3}."
40L		20 fr bot	Delete "used in training devices."
40R		12	Delete "training devices."
41L		1, 7, 9	In each of the three equations extend the square root symbol so that it embraces the entire expression after the "equal" sign and not just the numerator of the fractions. The equations near the bottom of the column illustrate how this should be done.
		8 fr bot	After "equal to" add ".707 of its peak value."
44R		24	Change "or" to "of."
50R		9 fr bot	Change "stated" to "started."
53R		33	Between "Increasing" and CEMF," insert "either or both of these factors increases."
54L		10	Between "speed regulation" and "The," insert this sentence: "When voltage is first applied to a series motor, a high starting current flows and a large starting torque is developed."
57R		2	Change "th" to "the."
		25 fr bot	Between "of" and "conductor" insert "a."
63R		16	Delete "field."
		30	Change "wats" to "watts."
		30,32	Change the "1" in each formula to "I."
64R		1–2 fr bot	Delete "to the ohmmeter."
66L		7	Change "no" to "an."

Page-Col	*Subject*	*Line(s)*	*Correction*
		11 fr bot	Change “decreased” to “decreases.”
66R		13	Change “point 3” to “point e.”
69L		2	Change “T0 to move toward T1” to “T1 to move toward T0.”
70R		3 – 4 fr bot	Delete “frequency circuits.”
72L		11 fr bot	Change “as” to “at.”
76R		4, 2 fr bot	In each line between “a” and “triangle,” insert “right.”
78L		8	Between “series” and “with,” insert “AC circuit with a resistor and a capacitor in series.”
79L		13	Between “the” and “frequency,” insert “reactance of a capacitor decreases as the.”
79R		6	Change “X_1” to “X_L.”
80L		15	Change “thousandths” to “thousands.”
82L		4	Change the “I_2^2” in the equation to “I_R^2.”
82R		13	Change “6.4 −51.3°” to “6.4 −51.3° amps.”
		7 fr bot	Change “$I_t =$” to “$I_L =$.”
83L		1	Close the parentheses after “.5.”
84L		3	Change “resistors” to “resistance.”
84R		7	Change “an” to “a.”
84R		11	Delete “By decreasing the frequency,” and capitalize “the.”
92L		8, 9	Change “the aircrew trainer” to “many systems.”
94L		12 – 13 fr bot	Change “few and few” to “fewer and fewer.”
94R		10	Change “ist” to “its.”
98L		21	Change “repidly” to “rapidly.”
102R		18 fr bot	Delete “in the mercury-vapor tube.”
103L		2	Change “dionized” to “de-ionized.”
104L		23	Space between “This” and “force.”
104R		21	Change “States” to “Stated.”
105R		4	Change “freelectron” to “free electron.”
108L		9	Change “holds” to “holes.”

Page-Col	*Subject*	*Line(s)*	*Correction*
		16 fr bot	Change “semiconductor;s” to “semiconductor's.”
108R		17 fr bot	Change “if” to “is.”
117L		11	Change “statis” to “static.”
119R		17 fr bot	Change “amd” to “and.”
120L		2	Between “and” and “is,” insert “.1mA of base current (point A in fig. 7-15) collector current.”
		7	Between “by” and “is,” insert “.2mA). This controlling effect for a common-emitter configuration.”
120R		2	Change “as” to “is.”
		10	Change “tranisstorized” to “transistorized.”
122L		18	Change “as” to “is.”
125L		16	Change “T_{20}” to “T_0.”
125R		13	Change “R_{1k}” to “R_k.”
		11 fr bot	Change “T_{22}” to “T_2.”
127R		12 – 13 fr bot	Delete “you may remember from an earlier volume that.”
133R		6 – 8 fr bot	Delete sentence “As we indicated . . . is a resolver.”
135R		25	Change “2 × 10” to “2 × 100.”
		26	Change “(19^3)” to “(10^3).”
138R		14 fr bot	After “occupies” change “1” to “2^1.”
141L		15 fr bot	Change the number “(1.724)” to “(1.1724).”
141R		3 fr bot	Change “.0068125” to “.0078125.”
142R		11 fr bot	Change “produce” to “product.”
152R		7	Change “couters” to “counters.”
155L		1 fr bot	Change “inputss” to “inputs.”
156L		6 fr bot	Change “NDR” to “NOR.”

Page Changes: done

Remove Pages	*Insert Pages*
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Preface

THIS THIRD volume of CDC 32551, *Avionics Instrument Systems Specialist*, is a review course in electronic principles. The review includes elementary topics, basic electronics, basic circuits, generators, motors, inductors, capacitors, saturable reactors, semiconductor devices, vacuum tubes, analog computers, and digital computers.

Code numbers appearing on figures are for preparing agency indentification only.

Direct your questions or comments relating to the accuracy or currency of this volume to the course author: 3360 TCHTG/TTGU-F, ATTN: MSgt Miller, Chanute AFB IL 61868. If you need an immediate response, call the author, AUTOVON 862-2041, between 0730-1630 (CST). *(NOTE: Do not use the suggestion program to submit changes or corrections this course.)*

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This volume is valued at 51 hours (17 points).

Material in this volume is technically accurate, adequate, and current as of July 1981.

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NOTE: In this volume, the subject matter is developed by a series of student-centered objectives. Each of these carries a three-digit number and is in boldface type. Each sets a learning goal for you. The text that follows the objective gives you the information you need to reach that goal. The exercises following the information give you a check on your achievement. When you complete them, see whether your answers match those in the back of this volume. If your response to an exercise is incorrect, review the objective and its text.

Fundamentals of Electronics

THROUGHOUT YOUR career in an electronics field, you will be required to maintain various electronic systems. It should be noted that good electronic repair persons are extremely valuable to the career field. This is due to the fact that there are many different types of equipment. A thorough understanding of the fundamentals of electronics will enable you to maintain any type of system.

To function at your highest level of competency, you must understand the fundamentals of electricity. By achieving each of the learning objectives outlined in this chapter, you will broaden your understanding of electricity and consequently, find that your job is easier. Good electronic personnel are in demand. Strive to learn all you can about this vast subject.

1-1. Direct Current and Resistance

In this section we discuss fundamentals of direct current (DC), resistance, resistor color coding, and basic circuit symbols and components.

400. Define conductor and state those factors relative to the production of electromotive force (EMF) and current flow.

Fundamentals of DC. A conductor is any material that has many free electrons. Silver, copper, and gold are good conductors. Copper is the most commonly used because of the three, it is least expensive. An insulator is a material with few free electrons. Rubber, mica, glass, dry wood, and plastics are examples of good insulators. Semiconductors are used with solid state devices; their resistivity and conductivity fall between insulators and conductors. Germanium and silicon are most used at present.

Now, let's take a good conductor and pay particular attention to the free electrons in it. We'll use copper, which has many free electrons (see fig. 1-1). Notice that the free electrons are evenly distributed in the conductor and are moving about randomly.

If positively and negatively charged rods are placed as shown in figure 1-1, an electric field exists between the ends of the conductor. The negatively charged rod repels the electrons in the conductor while the positively charged rod attracts these electrons. The movement of the free electrons is no longer totally random. There is a movement (drift) of free electrons toward the positive rod. Some electrons will enter the conductor from the negative rod and leave the conductor to enter the positive rod. This drift or movement of electrons is defined as current flow or electric current. The charge on the negative rod was used as a supply of electrons.

Now let's connect a conductor between the two terminals of a battery, as shown in figure 1-2. The positive and negative forces of the battery cause movement of electrons as shown. The excess electrons at the negative terminal repel electrons, and the deficiency of electrons at the positive terminal attracts electrons. An electron flow results, and this electron flow is called an electric current. The battery in figure 1-2 has caused a current flow through the conductor.

When an electron leaves the negative terminal, it immediately repels a free electron already in the wire. A chain reaction takes place almost instantaneously throughout the conductor. The direction taken by the electrons is from the negative terminal to the positive terminal, through the conductor as shown. Chemical action inside the battery causes electrons to move from the positive terminal to the negative terminal. This is the basis of the electron theory. Electrons always move from positive to negative inside a voltage source and from negative to positive in the external circuit.

We have pointed out that electron flow is called electric current. The unit of electron flow is the ampere. When we speak of amperes, we are referring to the intensity of the current flow in a conductor. The standard symbol for current is "I." The electrical energy or potential difference that causes current to flow is called electromotive force (EMF). (Consider EMF as an electron moving force.)

An electric charge, whether positive or negative, is a reserve of energy. This reserve energy is potential energy as long as it is not being used. The potential energy of a charge is equal to the amount of work done to create the charge and the unit of measure is the volt. The electromotive force of a charge is equal to the potential of the charge and is expressed in volts. You may see the term "volt" abbreviated with either an upper or lower case letter "V."

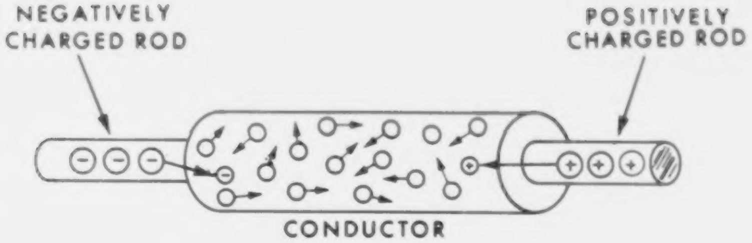


Figure 1-1. Negative and positive charged rods connected to a conductor.

The EMF of a voltage source is normally represented by the symbol "E" or "e."

When two unequal charges exist, the electromotive force between them is equal to their differences in potential. Since the potential of each charge is expressed in volts, the difference in potential is also expressed in volts.

Voltage, or a difference in potential, exists between any two charges that are not exactly equal. Even an uncharged body has a potential difference with respect to a charged body; it is positive with respect to a negative charge and negative with respect to a positive charge. A potential difference exists between two unequal positive charges or between two unequal negative charges. Thus potential difference or voltage is purely relative. It does not express the actual amount of charge but rather compares one charge to another and indicates the electromotive force between the two charges being compared. Using zero as a reference, for example, everything below zero is negative and everything above zero is positive with respect to the reference. However, 5 volts below 0 is positive with respect to 10 volts below 0. Likewise, 5 volts above 0 is negative with respect to 10 volts above 0.

Exercises (400):

1. What is a conductor?

2. How does electron flow occur in a conductor?

3. What is the direction of e[illegible]tron flow in an external circuit?

4. Using −3 volts as a reference, indicate the polarity and value of the following voltages:

   a. 6.

   b. −3.

   c. 11.

   d. −7.

   e. −4.

   f. 0.

5. Give the symbol for current.

6. Give the symbol for EMF.

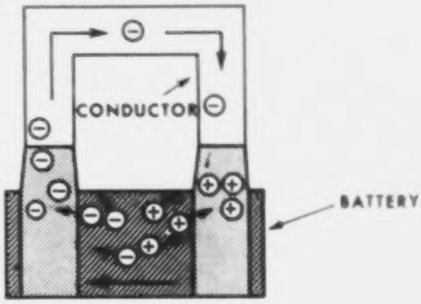


Figure 1-2. Battery connected to a conductor.

401. Define resistance, state the factors affecting it, and draw the symbols for resistors.

Resistance. Another aspect of electronics is electrical resistance. The opposition to current flow is known as resistance, and the unit of measure is the ohm. The symbol used to represent the ohm is the Greek letter omega (Ω). The letter "R" is used to designate resistance. For example, "R" might equal 2Ω, 5Ω, 100Ω, etc. Now the question is, how much opposition is 1 ohm of resistance? One ohm of resistance will allow one ampere of current to flow in a circuit when one volt is applied.

Factors Affecting Resistance. Experiments prove that the same voltage applied to electrical leads of different materials with exactly the same physical dimensions will produce different values of electrical current. Similarly, if a fixed voltage is applied to electrical leads of the same material, but different physical dimensions (length and diameter), the resulting electrical current will be different. On the basis of these effects, you can see that for a fixed voltage, the amount of current flowing through any material depends on the type of substance and the physical dimensions of the material. Another factor that limits current flow through a conductor is the temperature of the conductor. Let's take a look at each of these factors in turn.

Material. The material of which an object is made affects its resistance. The ease with which different materials give up their electrons is the determining factor.

Length. The next factor affecting the resistance of a conductor is its length. The longer its length, the greater the resistance. Let's cite an example. If a piece of copper wire 1000 feet long and having a resistance of 6 ohms is increased to 2000 feet, the resistance would increase to 12 ohms. Thus, the resistance of a conductor is directly proportional to its length.

Cross-sectional area. Another factor affecting the resistance of a conductor is its cross-sectional area. Let's cite an example of such a case. A piece of copper wire with a cross-sectional area of .1 square inch has a resistance of 6 ohms. Doubling the cross-sectional area to .2 square inches will decrease the resistance to 3 ohms, or one-half of its original value. Thus, the resistance of a conductor is inversely proportional to its cross-sectional area.

Temperature. The final factor affecting the resistance of a conductor is its temperature. For most materials, the hotter the material, the more resistance it offers. The colder the material, the less resistance it offers. The amount of resistance change per unit change in temperature is known as the temperature coefficient. If an increase in temperature causes the resistance to increase, the material is said to have a positive temperature coefficient. A material whose resistance decreases with an increase in temperature has a negative temperature coefficient.

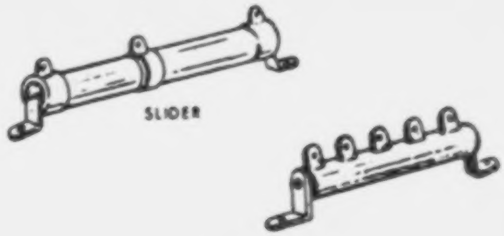
Resistors. A good conductor introduces very little resistance. However, a component to which the conductor is connected may offer a lot of resistance. One of these high-resistance components is called a resistor. The purpose of the resistor is to control the amount of current flow in the circuit.

Electronic equipment uses a wide variety of resistors. Some have a fixed-resistance value, and others are variable. Resistors are made of resistance wire, metal film, or carbon. Wire-wound resistors are used to control large amounts of current. Wire-wound resistors are constructed by winding resistance wire on a porcelain base. The ends of the wire are attached to to metal terminals. A coating is applied to the wire to protect it and conduct heat away.

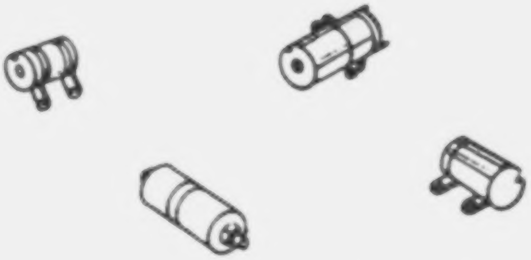
Two types of wire-wound resistors are shown in figure 1-3, A. Notice that one type has a slider and the other has fixed taps. These two arrangements allow the effective resistance to be changed.

Precision wire-wound resistors are illustrated in figure 1-3, B. These types of resistors are used when the resistance value must be very accurate, such as in test instruments.

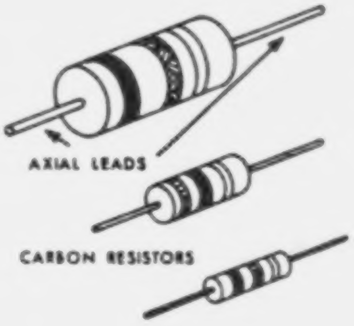
Composition resistors are shown in figure 1-3, C. The most common of these are carbon resistors, which are



A. WIRE WOUND



B. PRECISION WIRE WOUND



C-COMPOSITION

Figure 1-3. Resistors used in electronic circuits.

constructed of a rod of compressed graphite and a binding material. Wire leads are attached to each end of the rod. The rod is then covered with an insulating material. Figure 1-4 shows the schematic symbols for the resistors we have just discussed. You will find these schematic symbols used throughout electronic circuits.

Exercises (401):

1. Resistance is measured in what unit?

2. What is the resistance of a conductor directly proportional to?

3. What is the Greek symbol for resistance?

4. What is the resistance of a conductor inversely proportional to?

5. Define resistance.

6. Draw and label the schematic symbols for the following resistors:

    a. Variable.

    b. Tapped.

    c. Fixed.

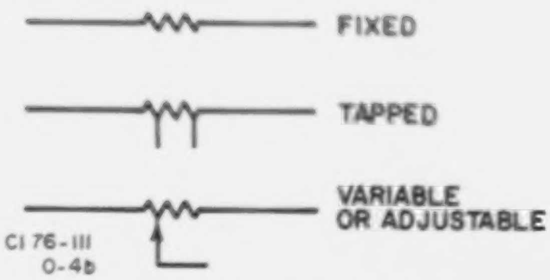


Figure 1-4. Resistor schematic symbols.

402. Calculate resistance values using resistive color codes and state the codes for given resistance values.

Resistor Color Coding. The published resistance of a resistor is indicated by its markings. Some resistors have the resistance value printed in ohms on the body of the resistor. Others have tags attached to indicate their value. However, composition resistors (carbon, for example) are so small that a printed marking is impractical, so a color code marking is used. Unfortunately, resistors are often mounted so that the printed marking cannot be seen or heat discolors the resistor body, making it difficult to read the color code. If you cannot determine the resistance visually, you must use a schematic diagram.

Table 1-1 shows the band color code system. The first three color bands shown on the resistor indicate the resistance in ohms. By substituting numbers from the color code chart, you can find the resistance value of a resistor. The first color band (nearest the end) is the first digit of ohmic value, the second color band is the second digit of ohmic value, and the third color band is how many zeros you will add.

If there are only three color bands, the tolerance is 20 percent. If a fourth band is present, it will be silver or gold. A silver fourth band indicates a 10 percent tolerance. A gold fourth band indicates a tolerance of 5 percent. Occasionally, you will find a gold or silver colored third band. This does not indicate the tolerance but instead tells you where to put the decimal point for the number determined from the first two color bands. If the third band is gold, the resistance is between 1 and 10 ohms; if it is silver, the resistance is between 0.1 and 1 ohm.

Figure 1-5 shows a composition-type resistor with three color bands. You read the color bands from the end toward the center. Using the values given in table 1-1, you would

TABLE 1-1
COLOR CODE FOR RESISTORS

COLOR	VALUE	COLOR	VALUE
Black	0	Green	5
Brown	1	Blue	6
Red	2	Violet	7
Orange	3	Gray	8
Yellow	4	White	9

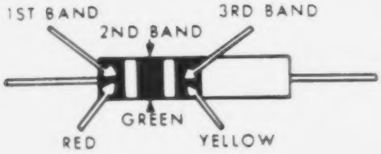


Figure 1-5. Composition resistor.

find the resistance to be 250,000 ohms. Since there is no fourth band, the tolerance is 20 percent.

20 percent of 250,000 = 50,000
Maximum resistance = 250,000 + 50,000
= 3000,000 ohms
Minimum resistance = 250,000 − 50,000
= 200,000 ohms

This resistor could have a resistance between 200,000 and 300,000 ohms and be within tolerance.

Exercises (402):

1. Calculate the values of the following resistors.

   a. Orange-blue-green-gold.

   b. Red-orange-red.

   c. White-gray-yellow-silver.

   d. Brown-black-silver-gold.

   e. Violet-violet-green.

   f. Red-red-gold-silver.

   g. Yellow-violet-black.

2. Give the color coding for the following resistor values. If no tolerance is given, assume it to be 20 percent.

   a. 2500.

   b. 6.

   c. 130,000 ± 10 percent.

   d. 10 ± 5 percent.

   e. 74,000.

403. Given a list of electronic components, draw the correct symbol for each and state the basic requirements of a practical circuit.

Basic Circuit Symbols and Components. You have seen how current flow is present when a conductor is connected between two charged bodies such as the two terminals of a battery shown in figure 1-2. However, the connection shown in figure 1-2 is not a practical basic circuit, as the two terminals will quickly neutralize the battery and render it useless. We must have some way to prevent this useless draining of the power source. Any electronic device that offers resistance to current flow may be used.

Essentially, the three requirements of a practical circuit are:

a. EMF source.
b. Conductor.
c. Resistance of some power dissipating device (resistor, bell, lamp, etc.).

Figure 1-6 is a schematic representation of such a circuit. Notice that symbols, rather than pictures are used to represent the electronic components. All electronic components have a symbol, and you must be able to recognize the symbol and relate it to the proper component.

Let's examine a few basic circuit symbols. Refer to each symbol in figure 1-7 as we describe each component.

Resistors. There are several varieties of resistors. The first resistor is the most common and comes in a wide range of ohmic values. The rheostat is a type of variable resistor. It is usually wire-wound and is available in only low-ohmic values. Another wire-wound device is the tapped resistor. Different amounts of opposition are sensed at its various taps. The potentiometer is either made of carbon or wire-

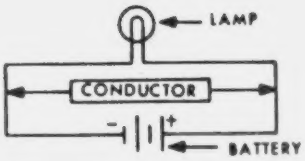

LAMP
CONDUCTOR
-
+
BATTERY

Figure 1–6. Basic circuit.

wound. This variable resistor is also available in a wide range of ohmic values.

Battery. This device converts chemical energy to electrical energy. In the single or multicell battery shown in figure 1-6, the short line represents the negative terminal and the longer line represents the positive terminal. The negative terminal of one cell is connected to the positive terminal of another cell, and so on.

Ground. A ground is a point in a circuit used as a common reference point from which voltages are measured. Voltages may be either positive or negative with respect to ground. You are probably familiar with the electrical ground on an automobile; the chasis is the common reference point.

Voltmeter. This component measures voltage in volts.

Ammeter. An ammeter measures current flow in amps.

Ohmmeter. An ohmmeter measures resistance in ohms.

Rotating machines. A generator converts mechanical energy to electrical energy. A motor converts electrical energy to mechanical energy.

Switches. A switch is a circuit controlling device or simply a means of turning the circuit power on and off. There are numerous switch combinations you will learn by association. The three illustrated here include: SPST, which means single pole, single throw; SPDT, which means single pole double throw; and DPDT, which means double pole double throw.

Lamp. A lamp can be used in a circuit as a loading device or to indicate a circuit condition.

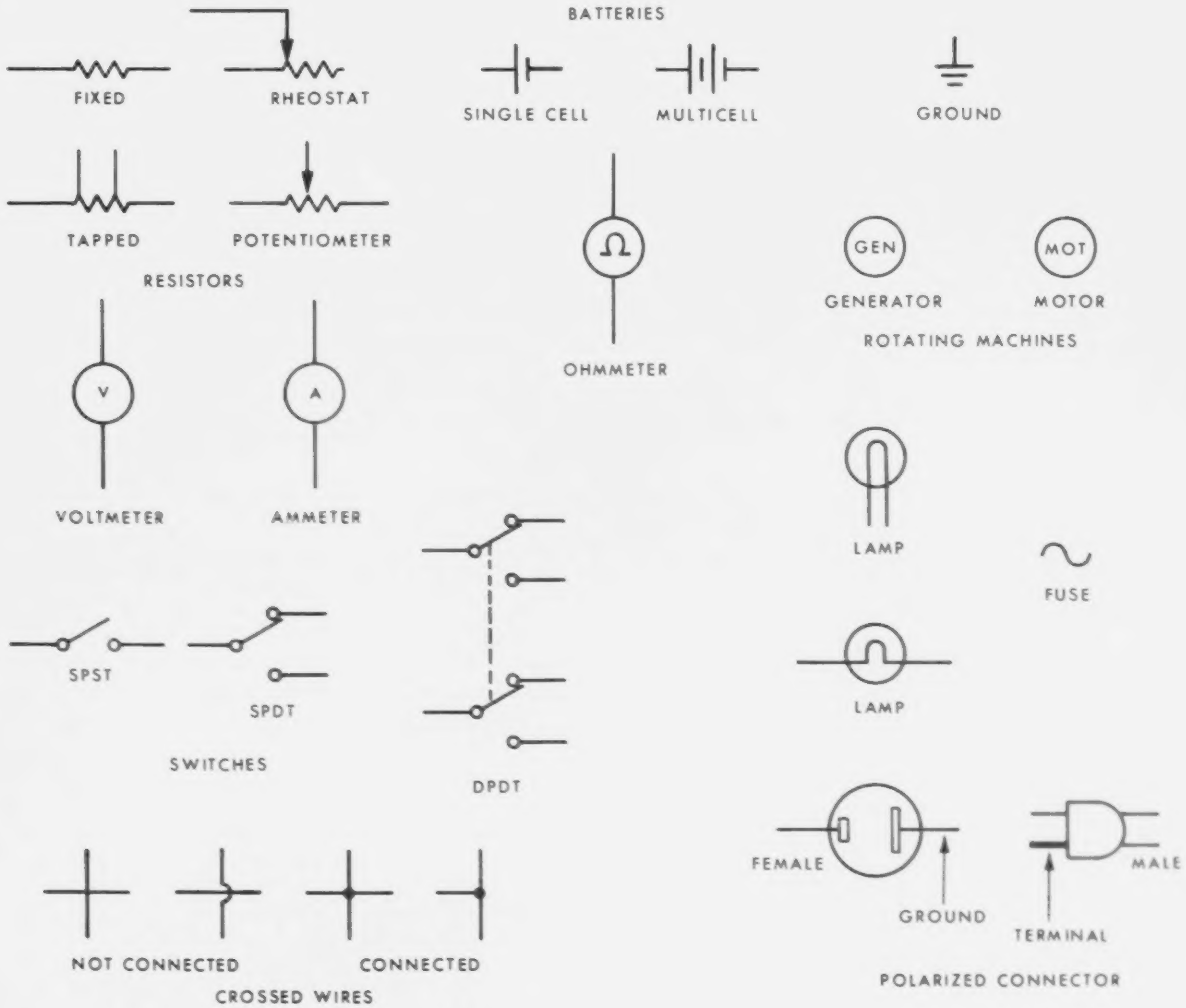

BATTERIES
FIXED
RHEOSTAT
SINGLE CELL
MULTICELL
GROUND
TAPPED
POTENTIOMETER
RESISTORS
Ω
OHMMETER
GEN
GENERATOR
MOT
MOTOR
ROTATING MACHINES
V
VOLTMETER
A
AMMETER
LAMP
FUSE
SPST
SPDT
SWITCHES
DPDT
LAMP
FEMALE
GROUND
MALE
TERMINAL
POLARIZED CONNECTOR
NOT CONNECTED
CONNECTED
CROSSED WIRES

Figure 1–7. Basic electronic symbols.

Fuse. A fuse is a protective device for the circuit in which it's located.

Crossed wires. To indicate that crossed wires do not connect, a dot is not placed at the junction where the wires cross. Some schematics may still use the older system of hooking one wire over the other to indicate the lack of a connection. Connected wires are shown by placing a dot at the junction where the wires cross.

Polarized connectors. This unit is used in conjunction with DC or AC circuits. In either case, the larger terminal on the male plug or the larger opening in the female plug is always the grounded terminal.

Exercises (403):

1. Name the three basic requirements for a practical circuit.

2. Draw the schematic symbols for the following:

   a. Ground.

   b. Rheostat.

   c. Ammeter.

   d. Battery.

   e. Crossed wires not connected.

   f. Lamp.

   g. SPDT switch.

   h. Fuse.

   i. Ohmmeter.

   j. Fixed resistor.

   k. Voltmeter.

   l. Tapped resistor.

   m. Crossed wires connected.

   n. Motor.

1-2. Working with Electric Problems

In this section we discuss using powers of 10 to simplify working with large numbers. We also discuss some simple equations used in electronics.

404. Calculate circuit values by using powers of ten, and define base number, exponent, and coefficient.

Powers of Ten. Electronic problems sometimes produce long equations. Using powers of 10 reduces the size of your equations. This simplifies the problems and reduces the chances of errors. We now review the way to convert any number to the standard power of 10 notation, multiply, divide, expand to powers, and extract roots of numbers expressed in powers of 10. A very important application of powers of 10 is the use of electronic prefixes to designate very small and very large numbers in electronic measurement. You must be able to convert standard prefixes to powers of 10 and powers of 10 to prefixes, and change either of these to numerical values. Finally, we review standard symbols with methods of connecting them in circuits to form simple electronic diagrams. Let's begin our discussion of powers of 10 by reviewing the definitions used in powers of 10.

Base number. The number to be multiplied by itself. In powers of 10, the base number is 10.

Exponent. The power of a number. The number of times a base number is multiplied by itself.

Numerical coefficient. The number preceding the base number and exponent.

When the base number 10 is expressed with an exponent, it is called a power of 10. This means that 10 is multiplied by itself the exponent number of times. For example:

$$10^1 = 10$$
$$10^2 = (10 \times 10) = 100$$
$$10^3 = (10 \times 10 \times 10) = 1000$$
$$10^4 = (10 \times 10 \times 10 \times 10) = 10{,}000$$

Notice in the preceding examples that the exponent equals the number of zeros in the final form of the number. Notice also that the exponents are all positive, resulting in very large numbers. You will also work with negative exponents that designate fractional or decimal numbers.

$$10^{-1} = \frac{1}{10} = 0.1$$
$$10^{-2} = \frac{1}{100} = 0.01$$
$$10^{-3} = \frac{1}{1000} = 0.001$$
$$10^{-4} = \frac{1}{10000} = 0.0001$$

You will find that fractional or decimal values as small as 10^{-6} or 10^{-12} are common in electronics.

Conversion of Powers of Ten. Any number can be expressed as a quantity between 1 and 10 if you multiply it by the proper power of 10. The standard method of conversion is to move the decimal point. Place the decimal so that one digit is to the left of the decimal; then multiply this by the proper power of 10 so that the value of the number does not change. Here are some examples of numbers expressed in powers of 10, using a numerical coefficient:

$$400 = 4 \times 10^3$$
$$435{,}000 = 4.35 \times 10^5$$
$$.002 = 2 \times 10^{-3}$$
$$.0000673 = 6.73 \times 10^{-5}$$

Now let's analyze the steps to take to make these conversions.

Numbers larger than one. The number 4000 is a whole number, with the decimal to the right of the last zero. To convert 4000 to a power of 10, move the decimal to the left until a number between 1 and 10 is reached. In this instance, move the decimal three places. This yields 4.000. To keep the value of the original number we must multiply by a power of 10. The exponent of 10 is the number of places the decimal has been moved. In this example, the decimal was moved three places. The power of 10 is shown as 10^3. The conversion then reads 4×10^3. Notice that we have not changed the value, since 10^3 is 1000 and 4 times 1000 equals 4000.

Let's convert 435,000 to powers of 10. The first step is to move the decimal until a number between 1 and 10 is reached. This number requires moving the decimal five places to the left; thus, 4.35 is the result. Since the decimal point was moved 5 places, the exponent is 5 and the power of 10 is 10^5. The full conversion reads 4.35×10^5.

Numbers smaller than one. The number .002 has the decimal point placed on the left. To convert this number to a power of 10, move the decimal to the right until a number between 1 and 10 is reached. This time we must use a negative exponent to keep the value of the original number. We moved the decimal 3 places to the right, the exponent is −3, and we express the power of 10 as 10^{-3}. Therefore, .002 is written as 2×10^{-3}.

Remember, the exponent is the number of places you move the decimal. Move it to the right, and the sign is minus; move it to the left, and the sign is plus.

For numbers already between 1 and 10, you do not move the decimal point at all. The exponent is zero. For example: 6.741 may be written as 6.741×10^0. Since $10^0 = 1$, we have not changed the value of the number.

Multiplication of numbers by Using Powers of Ten. Using powers of 10 can greatly reduce your effort in multiplication problems. For example, let's multiply 12,000 × 160,000. You should first express the numbers in powers of ten:

$$(1.2 \times 10^4)(1.6 \times 10^5)$$

Next multiply the numerical coefficients:

$$(1.21)(1.6) = 1.92$$

Then multiply the powers of 10 by adding the exponents:

$$(10^4)(10^5) = 10^{(4+5)} = 10^9$$

Combine the coefficient product with the power of 10 and state your final answer so the numerical coefficient will be left between 1 and 10. In this case, your answer is:

$$1.92 \times 10^9$$

Numbers less than 1 expressed in powers of 10 use a negative exponent. The number 0.00048 expressed in powers of 10 is 4.8×10^{-4}. To multiply two numbers that are both less than one, the numerical coefficients are multiplied and the exponents are added. In the problem $(2.5 \times 10^{-4})(2.1 \times 10^{-5})$, the numerical coefficients are multiplied to produce 5.25 and the power of 10 exponents are added to obtain $10^{[(-4)+(-5)]} = 10^{-9}$. The final expression is 5.25×10^{-9}.

Division with Powers of Ten. To divide 6000 by 300, we can mathematically express it as: $\frac{6000}{300}$. The first step is to convert 6000 to 6×10^3 and 300 to 3×10^2. Then, write the problem as:

$$\frac{6 \times 10^3}{3 \times 10^2}$$

The next step is to divide the numerical coefficient in the denominator into the numerical coefficient of the numerator. This part of the problem is written as:

$$\frac{6}{3} = 2$$

The next step is to divide the powers of 10 by subtracting exponents.

$$10^{(3-2)} = 10^1$$

There is an alternate method to solve this portion of the problem. A rule of exponents says a denominator can be moved to the numerator by changing the sign of the exponent. Therefore

$$\frac{6000}{3000} = 2 \times 10 = 20$$

By adding the exponents (multiplication of powers of ten), we arrive at the final solution.

$$10^{[(3)+(-2)]} = 10^1$$

Addition and Subtraction with Powers of Ten. A basic rule in all addition and subtraction is that you can only combine like quantities. In order to add or subtract numbers that contain powers of 10, it is necessary for the exponent of the 10 to be the same. Therefore, we add or subtract the numerical coefficients and keep the same exponent of 10. Our example below shows the addition of powers of 10. You can use the same example for subtraction by changing the plus to minus and complete the problem.

$$(6 \times 10^3) + (3 \times 10^3) = 9 \times 10^3$$

Squaring a Number Using Powers of Ten. To square or raise the power of a number to any value, the exponents are multiplied. For example, to square 2×10^3, we would write:

$$(2 \times 10^3)^2$$

The 2 squared equals 4. To square 10^3, multiply the exponents $10^{(3 \times 2)} = 10^6$. Express the answer in final form:

$$4 \times 10^6$$

Similarly:

$$\begin{aligned}(2 \times 10^{-3})^3 &= (2^1)^3 \times (10^{-3})^3 \\ &= 2(1 \times 3) \times 10^{[(-3)(3)]} \\ &= 2^3 \times 10^{-9} \\ &= 8 \times 10^{-9}\end{aligned}$$

Taking the Square Root of a Number Using Powers of Ten. To take the square root of a number with a power of 10, first take the square root of the numerical coefficient and then divide the exponent of 10 by 2. For example:

$$\begin{aligned}\sqrt{9 \times 10^4} &= \sqrt{9}\sqrt{10^4} \\ &= 3 \times 10^{(4/2)} \\ &= 3 \times 10^2\end{aligned}$$

Suppose we must take the square root of 3.6×10^7. or

$$\sqrt{3.6 \times 10^7}$$

To extract the square root, the exponent must be an even number. To convert to an even power of 10, move the decimal one place to the right:

$$36.0 \times 10^6$$

We can now extract the square root of 36, which is 6, and divide the exponent of 10 by 2. This gives us the answer of 6×10^3.

Exercises (404):

1. Define a base number.

2. Define an exponent.

3. What is a numerical coefficient?

4. Convert the following numbers to powers of 10:

   a. 2000.

   b. 158,342.

   c. 18,000.

   d. 0.1791.

5. Multiply the following. Express the answers in powers of 10.

   a. 716,000 × 1,820,000.

   b. $(2.7 \times 10^6)(3.1 \times 10^4)$.

   c. $(2.3 \times 10^{-4})(1.8 \times 10^{-6})$.

   d. $(6.7 \times 10^{-3})(2.8 \times 10^{-5})$.

6. Divide and express the answer in powers of 10.

$$\frac{21{,}000}{30}$$

7. Square the number and express your answer in powers of 10.

$$(6 \times 10^3)^2$$

8. Extract the square root and express your answer in powers of 10.

$$\sqrt{4.41 \times 10^6}$$

405. Use standard prefixes and symbols to express given electronic values.

Electronic Prefixes. You became acquainted with the electrical terms resistance, voltage, and current in previous discussions. Some other terms you will come in contact with are inductance, capacitance, power, and frequency. These are all terms referring to electrical values. Since these electrical values range from much less than unity to much greater than unity, specific prefixes and symbols are used to simplify expressing their values. This is when powers of 10 come into use.

Electronic technicians use certain powers of 10 so much that special names and symbols have come into use. The names are prefixed to the standard unit. For instance, a thousand is a very common multiple. The symbol for a thousand is "k" and its prefix is kilo. One thousand volts is called 1 kilovolt and is expressed as 1 kV. One thousand ohms is called 1 kilohm and is expressed as 1 kΩ. Quite often the symbol for kilo is an upper case K. For example, 1000 volts may appear as 1 KV or 1000 ohms may appear as 1KΩ.

Because prefixes represent specific powers of 10, they are very convenient to use. For example, kilo may be substituted for 10^3 in any numerical value. Therefore:

5×10^3 meters = 5 kilometers
10×10^3 watts = 10 kilowatts
38×10^3 ohms = 38 kilohms

Milli is equal to 10^{-3}. Therefore:

5×10^{-3} amps = 5 milliamps
430×10^{-3} volts = 430 millivolts
6×10^{-3} watts = 6 milliwatts

Now let's substitute 10^{-3} for milli:

5 milliamps = 5×10^{-3} amps or .005 amps
430 millivolts = 430×10^{-3} volts or .43 volts
6 milliwatts = 6×10^{-3} watts or .006 watts

Table 1-2 is a conversion chart that you should memorize for working with electronic problems.

Exercises (405):

1. Convert the following values as directed. Example: Change .006 amps to mA = 6 mA.

   a. 3000 ohms to k ohms.

   b. 60 kV to volts.

TABLE 1–2

SYMBOLS AND POWERS CONVERSION

Prefix	Symbol	Power of Ten	Numerical Equivalent
Tera	T	10^{12}	1,000,000,000,000
Giga	G	10^{9}	1,000,000,000
Mega	M	10^{6}	1,000,000
Kilo	K	10^{3}	1,000
Hecto	h	10^{2}	100
Deka	d or da	10	10
Deci	d	10^{-1}	0.1
Centi	C	10^{-2}	0.01
Milli	m	10^{-3}	0.001
Micro		10^{-6}	0.000,0001
Nano	n	10^{-9}	0.000,000,001
Pico	p	10^{-12}	0.000,000,000,001

c. 2 mA to amps.

d. .600 amps to mA.

e. 150 mW to kilowatts.

f. 10 M Ω to ohms.

g. 5 amps to μ amps.

h. 100 ohms to K Ω.

i. .002 mA to amps.

406. Define the terms "equation" and "axiom."

Simple Equations and Ohm's Law. Analyzing and solving electronic problems require the use of formulas which are expressed as equations. The following review of the techniques involved in solving equations will provide you with the basis for solving electronic formulas to find any quantity in terms of the other quantities involved.

Equations. An equation is a mathematical statement that two quantities are equal. The equal sign (=) is used to separate the two equal quantities. The quantity to the left of the equal sign in the equation $7 + 1 = 5 + 3$ is equal to the quantity to the right of the equal sign. Whenever you work an equation, think of it as a precision-balanced scale. The equation is balanced when you begin to work with it, and you must keep it in balance as you work toward a solution. You can add, subtract, multiply, divide, raise to powers, and extract roots within an equation, providing you do exactly the same thing to both sides of the equation.

Axioms. Equations are solved through the use of axioms. An axiom is a truth or fact that is self-evident and needs no proof. The various methods of solving equations are derived from the following axioms:

Axiom 1: If equals are added to equals, the sums are equal.

Axiom 2: If equals are subtracted from equals, the remainders are equal.

Axiom 3: If equals are multiplied by equals, the products are equal.

Axiom 4: If equals are divided by equals, the quotients are equal.

Axiom 5: Quantities equal to the same quantity or to equal quantities are equal to each other.

Axiom 6: Like powers of equal quantities are equal.

Axiom 7: Like roots of equal quantities are equal.

Applications of the foregoing axioms are illustrated below. Reread each axiom as you proceed through each illustration.

Axiom 1: Suppose that $X - 5 = 12$. If 5 is added to both sides:

$$\begin{array}{rcl} X - 5 & = & 12 \\ +5 & = & +5 \\ \hline X & = & 12 + 5, \text{ and } X = 7 \end{array}$$

Five has been added to both sides, but it appears that −5 has been moved from the left side to the right by changing its sign. This operation is called transposing.

Axiom 2: Suppose $X + 5 = 23$. Subtract 5 from both sides:

$$\begin{array}{rcl} X + 5 & = & 23 \\ -5 & = & -5 \\ \hline X & = & 23 - 5, \text{ and } X = 18 \end{array}$$

Here it is as if the 5 had been moved to the right side and its sign changed. This is another example of transposing.

Axiom 3: Suppose $\frac{X}{5} = 12$. Multiply both sides by 5:

$$(5)\frac{X}{5} = 12(5)$$

$$\frac{5}{5}X = 60$$

$$(\text{since } 5/5 = 1)\ X = 60$$

Axiom 4: Suppose $5X = 85$. Divide both sides by 5:

$$\frac{5X}{(5)} = \frac{85}{(5)}$$

$$X = 17$$

Axiom 5: Suppose $X = m$ and $Y = m$, then $X = Y$, for both were equal to m.

Axiom 6: Suppose $\sqrt{X} = 5$. Square both sizes.

$$(\sqrt{X})^2 = (5)^2$$

$$X = 25$$

Axiom 7: Suppose $X^2 = 36$. Take the square root of both sides.

$$\sqrt{X^2} = \sqrt{36}$$

$$X = 6$$

Transposing terms. In the illustrations of axioms 1 and 2, the addition or subtraction was equivalent to moving a term across the equal sign by simply changing the sign. This way the operation takes less time.

Suppose:

$$13X - 8 = 11 - 6X$$

Then:

$$13X + 6X = 11 + 8 \text{ (axiom 1)}$$

Also:

$$19X = 19 \text{ (adding like terms)}$$

and, therefore $X = 1$ (axiom 4)

Changing signs in an equation. All the signs in an equation can be changed by multiplying by -1. Thus

$$-8X + 40 = 2X - 10$$

Multiply by (-1)

$$8X - 40 = 2X + 10 \text{ (axiom 3)}$$

Exercises (406):

1. Define an equation.

2. Define an axiom.

407. Solve equations for one unknown, and apply Ohm's law to find the current in a given circuit.

Solving Simple Equations. By applying the axioms, transposing and cancelling, the solution of equations becomes a very simple operation.

Example 1: Given

$$\frac{3X}{4} = 27$$

Multiply by (4)

$$3X = 108 \text{ (axiom 3)}$$

Divide by (3)

$$X = 36 \text{ (axiom 4)}$$

Example 2: Given

$$3 - (X - 3) = 5 - 2X$$

Removing ( )

$$3 - X + 3 = 5 - 2X$$

Transposing

$$-X + 2X = 5 - 3 - 3$$

Therefore

$$X = -1$$

Example 3: Given

$$3(4S - 5) - 4(S - 6)$$
$$3(S + 1) + 1$$

Simplifying

$$12S - 15 - 4S + 24 = 3S + 3 + 1$$

Transposing

$$12S - 4S - 3S = 3 + 1 + 15 - 24$$

Collecting like terms

$$5S = -5$$

Divide by (5)

$$S = 1 \text{ (axiom 4)}$$

More often than not, in electronics we will be working with fractions.

Solving equations with fractions. To solve equations with fractions, you need to learn to change them to equivalent equations without fractions. To do this you multiply every term by the lowest common denominator. Now solve the resulting equation.

Example 1: Given

$$\frac{4y}{3} - \frac{3}{2} = \frac{y}{3} - 1$$

Multiple by (6)

$$\frac{24y}{3} - \frac{18}{2} = \frac{6y}{3} - 6$$

and

$$8y - 9 = 2y - 6$$

and

$$8y - 2y = 9 - 6$$

or

$$6y = 3$$

Therefore

$$y = \frac{1}{2}$$

Example 2: Given

$$\frac{5}{2y} + \frac{1}{2} = 7y - \frac{1}{5y}$$

Multiply by (10y)

$$\frac{5}{2y}(10y) + \frac{1}{2}(10y) = \frac{(7y - 1)}{5y}(10y)$$
$$25 + 5y = 14y - 2$$
$$+5y - 14y = -2 - 25$$
$$-9y = -27$$
$$y = 3$$

Solving equations with one unknown. Your work in electronics will involve many formulas that contain one unknown quantity. We must be able to rearrange these formulas to find any quantity in terms of the other quantities involved. This type of equation is called a lateral equation. We will use as an example Ohm's law formula of:

$$I = \frac{E}{R}$$

With this formula, you can rearrange the terms to solve for any term when given the other two.

Since we have named R as the unknown, the first step is to move it to the left side of the equation. To do this we use axiom 3. If you multiply both sides of an equation by the same value, you do not change the equality of the equation. In this instance, since R is in the denominator, we will multiply both sides by R. Now we have:

$$IR = \frac{ER}{R}$$

Because we have R in both the numerator and denominator on the right side, they cancel each other and we have:

$$IR = E$$

This is still not the solution, as we must finish with the R alone on the left side. To move the I to the right side, use axiom 4 and divide both sides by I as shown here:

$$\frac{IR}{I} = \frac{E}{I}$$

Now we have I in both the numerator and denominator on the left side, so they cancel each other. This leads to our solution, which is:

$$R = \frac{E}{I}$$

The next thing to learn is to solve for the numerator E in our original equation. This time multiply both sides by R. This puts R in the numerator and our problem is thus:

$$IR = \frac{ER}{R}$$

$$IR = E \text{ or } E = IR$$

As we have seen in the two previous examples, you can solve for one unknown when given two known quantities.

We have all heard the expression "rule of thumb." The formula $I = \frac{E}{R}$ is custom-built for conversion to a rule of thumb. If you put your thumb over the unknown quantity, the mathematical process to follow is clearly indicated. For example, if you want the equation for E, cover the E with your thumb. The mathematical process to find E is then clearly shown; it's I × R.

Now let's see how Ohm's law formula is applied to a simple electrical circuit. To use this formula remember that I is expressed in amps, E is in volts, and R is in ohms. Look at the circuit shown in figure 1-8. Notice is consists of a 6V batter, a switch, and a lamp with a resistance of 2 ohms. The problem is to find the current when the switch is closed. We know that I is equal to E divided by R. When we substitute the two known values for E and R, we have $\frac{6}{2}$. Therefore, $I = \frac{6}{2}$ or I = 3 amps.

Another equation you may use is $2\pi fCX_c = 1$. If you want to solve for f the first thing yo should think about is getting the f alone on the left side. The quickest, easiest, and best method is to divide both sides by everything on the left except the f. Let's see how this looks:

$$\frac{2\pi fCX_c}{2\pi CX_c} = \frac{1}{2\pi CX_c}$$

Look closely at the left side and you will see that everything will cancel out except the f. Therefore, we have our solution which is:

$$f = \frac{1}{2\pi CX_c}$$

The next type of equation you are to solve might appear to be slightly more complicated.

$$\frac{A}{B} = \frac{C}{D} \text{ (solve for A)}$$

Actually it is no more difficult than the other ones you've been solving. The two most important things to remember are:

(1) Whatever process you apply to one side of an equation must also be applied to the other side.

(2) Apply whatever axiom is necessary so that the unknown is by itself on the left side of the equation when you reach the final solution.

In order to leave A by itself on the left side, we must multiply both sides by B; we have:

$$\frac{AB}{B} = \frac{CB}{D}$$

The Bs on the left side cancel each other, and we have:

$$A = \frac{CB}{D}$$

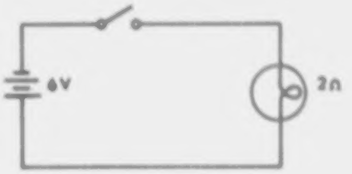


Figure 1-8. Basic DC series circuit.

Solving equations using cross multiplication. Let's look at the equation we just solved in a different way. A simpler solution involves a process known as cross multiplication. In cross multiplication you multiply the numerator on one side by the denominator of the other side. It works like this when solving for A:

$$\frac{A}{B} = \frac{C}{D}$$

Cross multiplying both numerators and denominators results in two values that are expressed as BC = AD. Now, to get rid of the D on the right side, divide both sides by D as shown below.

$$\frac{BC}{D} = \frac{AD}{D}$$

The two Ds on the right cancel and our solution is:

$$\frac{BC}{D} = A \text{ or } A = \frac{BC}{D}$$

Regardless of which side has the known value, the process is the same: Cross multiple to get rid of the fractions, and then divide to leave the unknown by itself.

Exercises (407):

1. Solve for the unknown in each of the following equations:

   a. $X + 10 = 18$

   b. $2X + 12 = 24$

   c. $3X - 6 = 9$

   d. $7X - X = 49 - X$

   e. $10X - 15 + 5 = 110$

   f. $3X + 10 = 1$

   g. $X + 16 = 11$

   h. $6X + 10 = 10X - 10$

   i. $4X - 8 = 2X + 10$

   j. $7X - 8 + 4 = 3X + 9 + 15$

   k. $10X - 4 = 100 + 16$

   l. $2X - 9 - 1 + 4 = 3X - 19$

2. In solving for A in the equation $\frac{A}{B} = \frac{C}{D}$, what is your first step?

3. If you apply 5 volts to a circuit that contains 50 ohms of resistance, what will the current be?

1-3. Magnetism

Magnetism, like electricity, is an invisible force that has been known for many centuries. However, its relationship to an electric force was not realized for some 2000 years. Early students of science believe that magnetism was a completely unrelated phenomenon. In modern science the connection between the two forces is apparent, for without magnetism, few of our modern electrical devices would be possible. Magnets or magnetic effects can be found in almost every modern electronic circuit in present-day use, ranging from a simple warning bell to the memory unit of digital computers.

408. Define magnetism, name the types of magnets, and state their characteristics.

Natural and Artificial Magnets. Magnetic lodestones, such as those found by the ancient Greeks, are considered to be natural magnets. These stones can attract small pieces of iron in a manner similar to the magnets that are common today. However, the magnetic properties of the stones were products of nature and not the result of the efforts of man. The Greeks called these substances magnetic. However, such magnets now have little practical use, for we can easily produce more powerful artificial magnets. These are usually chemical alloys of magnetic materials and are referred to as artificial magnets.

Artificial magnets are usually classified as permanent or temporary, depending on their ability to retain their magnetic properties after the magnetizing force has been removed. Magnets made from substances such as hardened steel and certain alloys retain a great deal of their magnetism. Thus, they are called permanent magnets. These materials are relatively difficult to magnetize because of the opposition offered to the magnetic lines of force as the lines of force try to distribute themselves throughout the material. This opposition the material offers to the magnetic lines of force is called reluctance. All permanent magnets are produced from materials having a high reluctance.

A material with a low reluctance, such as soft iron or annealed silicon, is relatively easy to magnetize but will retain only a small part of its magnetism once the magnetizing force is removed. Materials of this type that easily lose most of their magnetic strength are called temporary magnets. The amount of magnetism that remains in a temporary magnet is referred to as a residual magnetism. The ability of a material to retain an amount of residual magnetism is called the retentivity of the material.

Magnets are also described in terms of the permeability of their materials, or the ease with which magnetic lines of force distribute themselves throughout the material. A permanent magnet, which is produced from a material with a low reluctance, would have a high permeability.

Magnetic poles. The magnetic force surrounding a magnet is not uniform. There exists a great concentration of force at the ends of a magnet and a very weak force at the center. Proof of this can be obtained by covering a glass with iron filings and placing the glass on top of a bar magnet (see fig. 1-9). Many filings cling to the ends of the magnet, while very few adhere to the center. The two ends, which are the regions of concentrated lines of force, are the north and south poles of the magnet. Both poles have equal magnetic strength.

If a bar magnet is suspended freely on a string, it will align itself in a north and south direction. When this experiment is repeated, the same pole of the magnet will always swing toward the north pole of the earth. Therefore, it is called the north-seeking pole or simply the north pole. The other pole of the magnet is the south-seeking pole or the south pole.

Magnetic fields. The space surrounding a magnet where magnetic forces act is known as the magnetic field. A pattern of this directional force can be noted in figure 1-9. If the glass is tapped gently, the iron particles will align themselves with the magnetic field surrounding the magnet. The filings form a definite pattern, a visible representation of the forces comprising the magnetic field. The arrangement of the iron filings in figure 1-9 indicates that the magnetic field is very strong at the poles and weakens as the distance from the pole increases. You can see that the magnetic field extends from one pole to the other, constituting a loop about the magnet.

Magnetic Shielding. There are no known insulators against magnetic flux. Any material, when placed within a magnetic field, will be penetrated by the passage of magnetic flux. Thus, protection from magnetic forces is obtained by redirecting the field. If a magnetic material such as soft iron is placed within a magnetic field, most of the lines of force (which take the easiest path) will pass through the magnetic material while completing a closed loop.

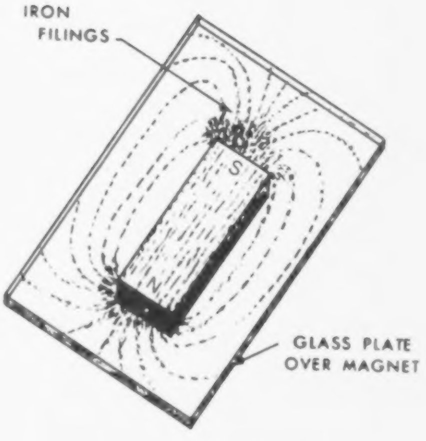


Figure 1–9. Magnetic lines of force.

Redirecting the magnetic field is necessary to protect the sensitive mechanism of electronic equipment. Such equipment becomes inaccurate under the influence of stray magnetic fields. Therefore, if we surround the equipment with a material having a high permeability, the magnetic lines will flow through the surrounding material.

Care of Magnetic Materials. A piece of steel that has been magnetized can lose much of its magnetism by improper handling. If it is jarred or heated, it will lose some of its magnetism. If this steel formed the horseshoe magnet of a meter, the meter would no longer give accurate readings. Therefore, use care in handling instuments that contain permanent magnets. Severe jarring or high temperature will damage the device.

Exercises (408):

1. What is magnetism?

2. Name two types of magnets.

3. Name two types of artificial magnets.

4. What is reluctance?

5. What is residual magnetism?

6. What is retentivity?

7. What is permeability?

8. What are the regions of a magnet in which the lines of force concentrate?

9. How may sensitive instruments be protected from stray magnetic fields?

10. Name two things that will damage a magnet and cause it to lose its magnetism.

409. Define electromagnet and explain its characteristics.

Electromagnetism. Let's explore the idea of electromagnetism, by first examining an electromagnet. An electromagnet is an electrically excited magnet capable of exerting mechanical force. Present-day examples of electromagnets include the starter solenoid on an automobile, electromechanical input-output devices used with computers, and the simple doorbell. There are many more. Each of these devices operates on the principle of a current carrying conductor wrapped around a soft iron core.

Magnetic field about a straight wire. We can prove the existence of a magnetic field surrounding a conductor carrying DC. Figure 1-10 illustrates the experimental procedure used. Note that a straight piece of wire is passed through a hole in a piece of glass and connected to a source of DC through a rheostat and switch. If we sprinkle iron filings over the glass and then tap it gently, the filings will arrange themselves in circles about the wire. If two magnetic compasses are placed on the glass, the compass needles will point in the direction of the magnetic lines of force as shown in figure 1-10. The north pole of each compass indicates the direction of magnetic lines of force.

In this experiment the magnetic lines of force travel counterclockwise. The experiment shows that a magnetic field does exist about a current carrying conductor and that the field has direction. If the battery is reversed, the direction of the current in the circuit is reversed. The direction of both compass needles will then change by 180°. Thus, a change in the direction of current produces a change in the direction of the magnetic field. The important point to remember with respect to the above experiment is that whenever an electric current is flowing, a magnetic field exists.

Magnetic field about a coil of wire. Let's take a straight wire and form it into a loop as in figure 1-11. The magnetic lines around the wire are as shown. With current flowing in it, the loop of wire acts like a short bar magnet. The face of the loop that the lines enter is the south pole and the face that they leave is the north pole.

If you wind several loops to form a coil or solenoid as shown in figure 1-12, a more powerful magnetic field will be created. Inside the coil, the lines are concentrated to form a power field, while outside the coil they are spread out.

A coil like that of figure 1-12 with current flowing in it is the equivalent to a bar magnet. Its magnetic field has the same shape as the field of a bar magnet, and it obeys the same laws of magnetism that a bar magnet obeys. That is, the unlike poles of two coils attract each other and the like poles repel. If the coil is free to rotate in a horizontal plane and is placed in a magnetic field, it will rotate, as will a compass needle, until the lines inside the coil are parallel to the lines of the field.

Electromagnets. Very strong electromagnets can be made by winding the coil around a piece of iron or steel. The reluctance of iron or steel is so much lower than air that

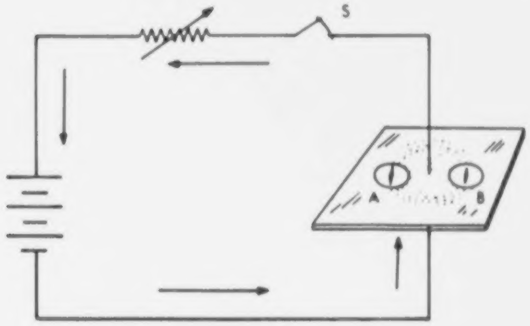


Figure 1-10. Magnetic lines of force.

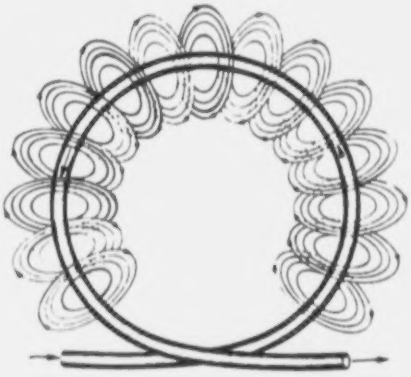


Figure 1-11. Left-hand thumb rule around a coiled wire.

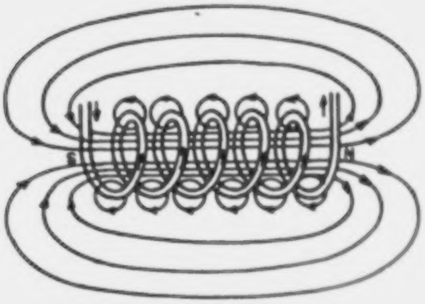


Figure 1–12. Magnetic field about a coil or wire.

the same electric current in the coil sets up thousands of times more lines of magnetism than with an air core. Of course, the larger the electric current, the more lines that will be set up in the core and, thus, the more powerful will be the magnetic field. Also, the more turns of wire wrapped around the core, the stronger the field. A field of a given strength can be produced by using many turns of wire carrying a small current or by using few turns of wire carrying a larger current. Thus, an electric current of 2 amperes flowing in a coil of 5000 turns will produce the same number of lines as a current of 20 amperes flowing in a coil of 500 turns. The product of the number of turns in a coil and the amperes flowing in the coil is called the ampere-turns of the coil. Two coils with the same number of ampere-turns will, if their cores are identical, produce magnetic fields of the same strangth. The same product of amperes and turns gives the same effect, no matter what the separate values of current and turns may be.

If, in a coil with an iron core, the current is continually increased, a point is reached eventually where further increases in current add very few lines to the flux already in the core. At this point it becomes uneconomical and impractical to attempt to add more lines, and the core is said to be *saturated*. Sometimes, the current in the coil is deliberately made large enough to saturate the core, but this is usually undesirable.

Now let's place a bar of iron or soft steel in the magnetic field of a coil as shown in figure 1-13. The bar will become magnetized. Since the bar has less reluctance than air, magnetic lines flow through it. If the field is strong enough, the tendency of magnetic lines to shorten themselves causes the bar to be pulled into the coil until its center is near the center of the coil (where the field is most intense). If you place the bar on the other side of the coil, it will also be drawn into the coil. The bar becomes magnetized by the field of the coil in such a way as to be attracted into the coil.

Exercises (409):

1. What is an electromagnet?

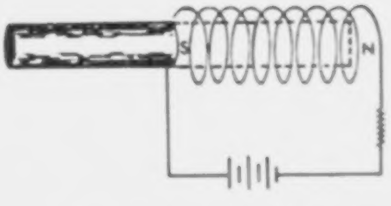


Figure 1–13. Action of an electromagnet.

2. If a piece of wire with electron flow in it is made into a coil, what type of magnet does it resemble?

3. If we put a piece of iron or steel through such a coil, we produce which type of magnet?

4. What does the term "saturated" mean when used with electromagnets?

5. Explain the action of an electromagnet.

410. State what electromagnet relays do, how they operate, and how to troubleshoot them.

Electromagnetic Relays. Many electrical devices use electromagnetism in their operations. Circuit breakers sometimes operate on this principle as do relays and certain types of meters. For us, the most important use of this action is in a remote control switch, called a relay. While relays come in many different sizes and shapes and are used for many different purposes, they all operate on the principle that iron is attracted to a pole of an electromagnet. A relay consists essentially of a coil with an iron core and moveable iron bar. When current flows in the coil, electromagnetism pulls the moveable bar toward the core. The movement of the bar opens or closes a circuit.

Figure 1-14 shows a basic relay and relay circuit. The relay itself has five main parts: core, coil, armature,

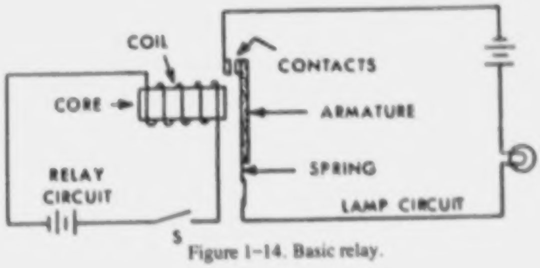


Figure 1–14. Basic relay.

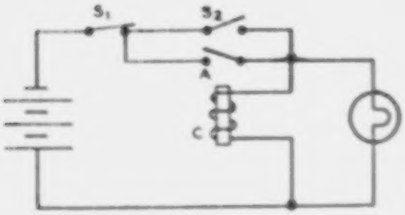


Figure 1-15. Holding relay.

contacts, and spring. When switch S is closed, current flows through the coil and causes a strong magnetic field to be set up around the coil. This magnetic field pulls the armature toward the core of the coil, closing the contact points and completing a path for current in the lamp circuit. Closing the relay circuit controls the lamp circuit, and the lamp glows. When switch S is opened, the field about the electromagnet collapses, the spring pulls the armature contacts apart and the lamp circuit opens.

Another relay circuit is shown in figure 1-15. The closing of switch S2 will permit current to flow in coil C. The contact arm (which contains iron) will be attracted toward the upper end of the electromagnet, thus closing the circuit at A. This permits a complete path for current in coil C and in the lamp circuit. The lamp will glow. Now opening the switch S2 will not open the coil or lamp circuit. In order to do this, switch S1 must be opened. This is the action of a holding relay.

An electronic relay circuit may be used to change a pure direct current into a pulsating direct current (see fig. 1-16). The circuit consists of a double-pole single-throw relay with one set of NC (normally closed) contacts and one set of ND (normally open) contacts. The relay coil is connected in series through the NC contacts. Thus, when switch S is closed, current will flow through the coil and through the NC contacts. Notice that a load device (R_L), in this case a resistor, is connected across the battery through the NO set of contacts. After switch S is closed (and before the relay energizes) no current can flow through R_L. As soon as the relay energizes, the NO contacts close, completing a path for current through R_L. Current will continue to flow through R_L until the relay armature returns to the deenergized position. At this time current ceases to flow through R_L. The voltage developed across R_L will vary intermittently between 0 and 12V; 0V when the relay is energized. As long as switch S is closed, the relay will continue to vibrate. The voltage appearing across R_L is a pulsating direct current. The number of pulses produced per second in a given period of time is determined by the frequency at which the relay armature vibrates.

Another application of an electromagnetic relay is its use as a protective device, similar to a fuse. Refer to figure 1-17. When switch S is closed, current flows through the relay coil and load device (R_L). Let us assume normal circuit current is 10 mA. Let us alos assume that relay requires 20 mA through the coil before it will energize. Suppose the load device resistance partially shorts out, causing the circuit current to exceed 20 mA. The relay energizes and interrupts the path for current. Once energized, the mechanical latch locks the armature in the open position. After the trouble has been corrected, the reset button can be pushed to unlock the armature. It then returns to its NC position. The action of the relay described here is that of an overload relay with manual reset. More elaborate overload relay circuits often use an automatic reset feature.

A relay should be inspected and checked thoroughly and frequently to insure trouble-free operation. You should make a visual check of the contacts with a magnifying glass. If you find an oxide coating or carbon deposit, use a relay burnishing tool to wipe the contacts clean. Never file the contacts. Check armature spring tension. A weak spring or improper adjustment of spring tension could cause the relay to chatter. Check the relay coil for signs of overheating. A partially shorted coil could cause chatter, hum, or reduced magnetic pulling power. An open coil would result in the relay's failure to energize. When in doubt as to the electrical continuity of the coil, check its resistance with an ohmmeter and compare the measured reading against the manufacturer's specified value. A relay seldom, if ever, requires lubrication. Following good preventive maintenance techniques will assure relay reliability.

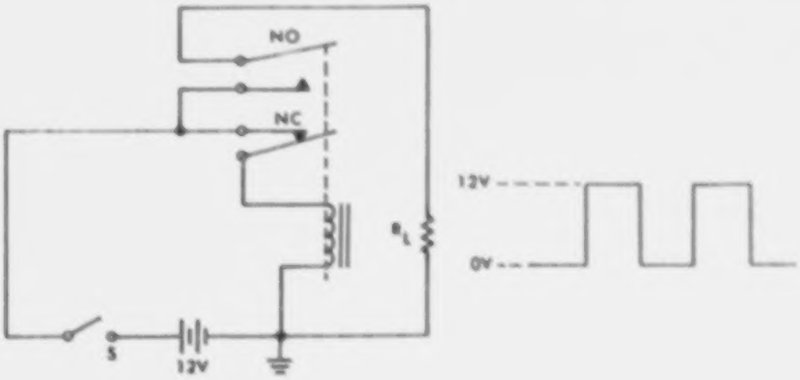


Figure 1-16. Vibrator used to obtain pulsating DC

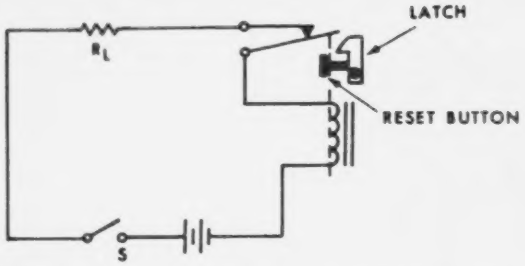


Figure 1-17. Electromagnetic relay used as a protective device.

Exercises (410):

1. How does a basic relay work?

2. What type of relay would you use to transfer a circuit formation from one condition to another?

3. Relays are normally shown in what position?

4. What device may be used to change a pure direct current into a pulsating direct current?

5. What type of relay may be used to replace a fuse in an electrical circuit?

6. What tool should you use to remove an oxide coating or carbon deposit on a relay contact?

7. What would be the symptoms of a relay with a partially shorted coil?

8. If the relay failed to energize, what would be a probable cause?

9. How could you check for the condition of a relay with an open coil?

DC Circuits

THE MOST BASIC circuit in electronics is the series circuit. No matter how complex a circuit gets, it still boils down to a collection of interconnected series circuits. Therefore, it's essential that you thoroughly understand what makes up a series direct current circuit, how current flows in the circuit, and how factors affect the current flow. This knowledge will be a tremendous asset as you study more complicated parallel any series-parallel DC circuits. You will also study the practical application of DC in voltage divider and bridge circuits.

2-1. DC Series Circuits

In this section we discuss series-resistive circuits, Kirchoff's laws, electrical power and energy, and Joule's law on electrical power.

411. Calculate the voltages, current, and resistance in a series DC circuit, and state Kirchoff's laws.

Requirements of a DC Series Circuit. Figure 2-1,A, shows a DC circuit. It is a series circuit because there is only one possible path for current to flow and because it contains the three basic requirements for any circuit:

(1) A source of power (battery).
(2) A load device (resistor).
(3) A conductor (wire).

You will find that most practical circuits also contain a safety device (fuse) and a control device (switch).

Current, Resistance, and Voltage in Series DC Circuits. We will examine the behavior of current, voltage, and resistance in a series circuit. Let's consider current first with the aid of figure 2-1,A.

Current flow. If we close the switch completing the circuit, current will flow. The three ammeters will show the same amount of current flowing. This is the first important thing to remember about a series circuit—current is the same at all points throughout a series circuit. Notice, we haven't said how much current is flowing. We have merely said that whatever the current is, it's the same everywhere in the circuit. Let's solve the simple circuit shown in figure 2-1,B. In order to find the total current, we must first find the total resistance. Total resistance (R_t) in a series circuit equal the sum of the individual resistances.

$$R_t = R_1 + R_2 + R_3 + \ldots$$

In our sample circuit,

$$R_t = 5\Omega + R_2$$
$$R_t = R\Omega + 10\Omega$$
$$R_t = 15\Omega$$

The resistance of the battery, switch, and fuse is considered to be negligible in this circuit, but in highly critical circuits, they must be considered. Now let's use Ohm's law to determine the current flow in the circuit. We will use Ohm's law formula:

$$I = \frac{E}{R}$$

Our battery voltage (E_a) is 30 volts and total resistance (I_t) is 15Ω, so we can substitute:

$$I_t = \frac{E_a}{R_t} \text{ or } I_t = \frac{30V}{15} \text{ or } I_t = 2 \text{ amps}$$

Current is 2 amps, and this is the series flow of electrons, everywhere in the circuit.

Resistance. Now consider how a change in resistance will affect current flow. For example, when voltage remains constant and the resistance is doubled, current is reduced to one-half of its original value. Let's assume that the resistance of our circuit in figure 2-1,B, is 30 ohms. Since the voltage remains constant:

$$I_t = \frac{E_a}{R_1} \text{ or } I_t = \frac{30V}{30\Omega} \text{ or } I_t = 1 \text{ amp}$$

On the other hand, if the voltage remains constant and the resistance is reduced to one-half of its original value, the current doubles its original value.

Voltage. Now, let's discuss voltage in a series circuit. The sum of the voltages dropped across each component of series circuit is equal to the applied voltage. This is expressed as follows:

$$E_a = E_{R_1} + E_{R_2} + \ldots$$

In our simple circuit, shown in figure 2-1, we know that E_a is 30 volts. Thus, the voltage dropped across resistors R_1 and R_2 add up to 30 volts. By using Ohm's law, we can find the exact voltage drop across each resistor.

We know I_t is 2 amps, and we know that

$$I_t = I_{R_1}$$

$$I_{R_1} = 2 \text{ amps}$$

$$\text{and } I_{R_2} = 2 \text{ amps}$$

With this information, we can calculate the voltage dropped across each resistor:

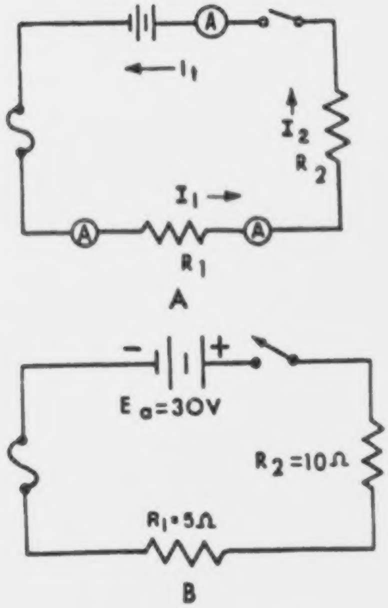


Figure 2-1. Series DC circuits.

$$E_{R_1} = I_{R_1} \times R_1$$

$$E_{R1} = 2A \times 5\Omega$$

$$E_{R_1} = 10V$$

$$E_{R_2} = I_{R_2}\ R_2$$

$$E_{R_2} = 2A \times 10\Omega$$

$$E_{R_2} = 20V$$

If we add the voltages dropped across the two resistors (10V + 20V), we get 30 volts, the same as our battery.

Changing the applied voltage will have a definite effect on the circuit. By using Ohm's law you can see a direct relationship between voltage and current. Taking our simple circuit in figure 2-1, assume that the voltage is doubled and the resistance is held constant:

$$I_t = \frac{E_a}{R_t} \text{ or } I_t = \frac{60V}{15\Omega} \text{ or } I_t = 4 \text{ amps}$$

If the voltage is reduced to one-half of its original value and the resistance held constant, the current decreases to one-half of its original value:

$$I_t = \frac{E_a}{R_t} \text{ or } I_t = \frac{15V}{15\Omega} \text{ or } I_t = 1 \text{ amp}$$

You will run into other types of problems that require a little mental flexibility on your part. Before making false starts, always examine the circuit to see what is known. Remember, any time we have two knowns, we can always solve for the unknown.

Up to this point in our analysis of series circuits, we have been mentioning only Ohm's law. Before going on, we should take time out and introduce another law that you have already applied in the solution of our series DC circuits.

Kirchhoff's laws. In 1847, a German physicist, Gustav Richard Kirchhoff, developed what is known as Kirchhoff's laws for current and voltage. These laws may be stated as follows:

a. The algebraic sum of the currents at any junction of conductors is zero. This means that the sum of all currents flowing to a point must be equal to the sum of all currents flowing away from that point.

b. The algebraic sum of the applied voltage and the voltage drops around any closed circuit is zero. This means that in any closed circuit, the applied voltage is equal to the sum of the voltage drops around the circuit.

In our previous analysis of DC series circuits, you found that the total current flows through each resistor in a series circuit, regardless of size or number of resistors. So, current is the same throughout the circuit. This is a direct application of Kirchhoff's first law. We will discuss further applications of this law in later sections of this chapter dealing with parallel DC circuits.

Kirchhoff's second law states that the applied voltage is equal to the sum of the individual voltage drops in a closed circuit. Referring to our discussion for figure 2-1, you will find the application of Kirchhoff's second law. The applied voltage was 30 volts. We found the voltage drop across R_1 to be 10 volts and the voltage drop across R_2 to be 20 volts. The total voltage drop, then, was 30 volts, the same as the applied voltage.

Now, let us solve a problem when the applied voltage is the unknown quantity. We will use both Kirchhoff's and Ohm's laws to check our solution.

Refer to figure 2-2. Since the current through resistor R_1 is known (2 amps), the total current of the circuit is known (Kirchhoff's first law). By using the total resistance equation, we find the total resistance (30 ohms). Now calculate the applied voltage using Ohm's law (E = IR). Then, we solve for the applied voltages with Kirchhoff's law (by taking the sum of the voltage drops in the loop) and see if our answers are the same.

Solving with Ohm's law: E = IR, first determine total resistance.

$$R_t = R_1 + R_2 + R_3 + R_4 + R_5$$
$$R_t = 2\Omega + 6\Omega + 4\Omega + 10\Omega + 8\Omega$$
$$R_t = 30\Omega$$

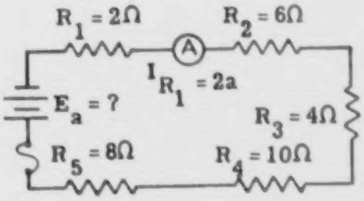


Figure 2-2. Application of Kirchhoff's and Ohm's laws.

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since

$I_t = 2$ amps

and

$E_a = I_t R_t$

$E_a = 60$ volts

Before applying Kirchhoff's second law, you must first use Ohm's Law (E = IR) to find the individual voltage drops. Using this formula, you will find the voltage drops across the resistors:

Voltage drop across R_1 (E_{R1}) = 4 volts
Voltage drop across R_2 (E_{R2}) = 12 volts
Voltage drop across R_3 (R_{R3}) = 8 volts
Voltage drop across R_4 (E_{R4}) = 20 volts
Voltage drop across R_5 (E_{R5}) = 16 volts

Applying Kirchhoff's second law:

$$E_a = E_{R1} + E_{R2} + R_{R3} + E_{R4} + R_{R5}$$
$$E_a = 4V + 12V + 8V + 20V + 16V$$

$$E_a = 60 \text{ volts}$$

Exercises (411):

1. Name the components of a basic series DC circuit.

2. Using the circuit in figure 2-3, calculate the unknown values.

3. Briefly state Kirchhoff's law on current.

4. Briefly state Kirchhoff's law on voltage.

412. Calculate the power dissipated by individual resistances as well as the total power dissipated in a given series circuit.

Electrical Power and Energy. Power is the rate of doing work per unit of time. Work results from a force acting on a mass over a distance. The operation of electrical circuits involves a force (voltage) acting on a mass (electrons) over a distance. The amount of time required to perform a given amount of work determines the energy expended. Since energy is the capacity to do work, power can also be defined as the time rate of developing or expending energy. In electrical circuits, electrical energy is transformed into heat energy. Following the law of conservation of energy, the heat energy will be equal in value to the electrical energy causing it. Therefore, by measuring the amount of heat energy given off by an electrical circuit in a given amount of time, you can calculate the amount of electrical power consumed in the circuit.

Joule's Law on Electrical Power. An experiment measuring the heat given off by an electric circuit was performed by an English physicist, James Joule, in 1843. He experimentally proved that the amount of heat produced by an electrical circuit was dependent upon current and resistance. This proportional relationship is known as Joule's law: "The amount of heat produced by a circuit element is directly proportional to resistance, the square of the current, and time." The equation for the law is:

$$\text{Heat} = I^2R_1 = \text{Power}$$

By substituting Ohm's law values into the power formula developed from Joule's law, we can derive the following equation:

Substituting $I = \frac{E}{R}$ (Ohm's law) into

$$P = I^2R$$

then

$$P = \left(\frac{E}{R}\right)^2 R$$

or

$$P = \frac{E^2R}{R^2}$$

and

$$P = \frac{E^2}{R}$$

The resultant equation is useful when the resistance and voltages are known. The power formula can also be expressed as an equation in terms of current and voltage:

Substituting $R = \frac{E}{I}$ (Ohm's law) into

$$P = I^2R$$

then

$$P = I^2 \frac{E}{I}$$

and

$$P = IE$$

The unit of measure for electrical power is the watt. The watt represents the rate at any given instant at which work is being done in moving electrons through a circuit. The

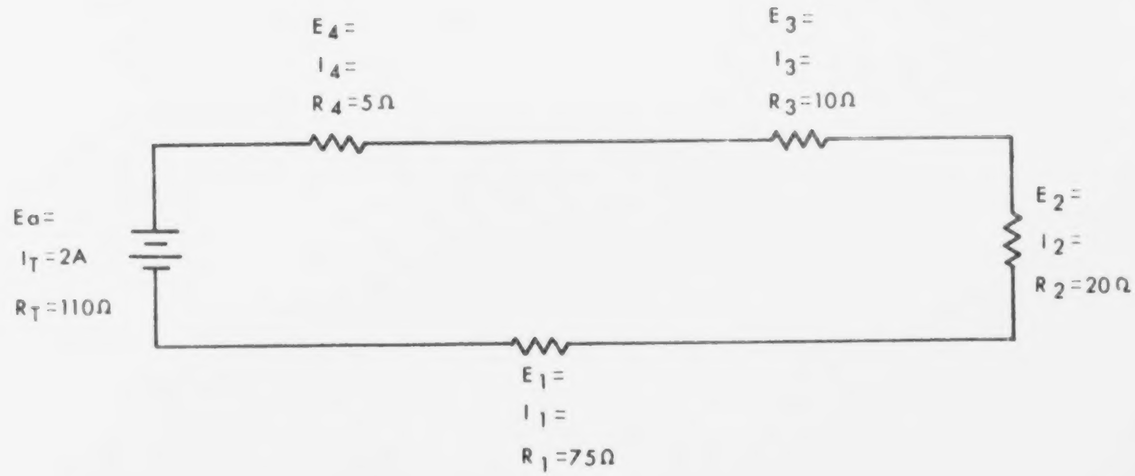

Figure 2–3. Series circuit.

previous examples demonstrate that any form of the power formula may be used to find power in a circuit. Likewise, if the power dissipated in a simple circuit is known and the value of any one of the other circuit quantities is known (E, I, or R), the value of the remaining quantities can be found. To see how this is done, we first calculate for voltages.

The power dissipated by the 1-ohm resistor in figure 2-4 is 25 watts. The value of voltage in the circuit is calculated as follows:

$$P = \frac{E^2}{R}$$

$$E^2 = PR$$

$$E = \sqrt{PR}$$

$$E = \sqrt{25\,(\text{watts}) \times 1\,(\Omega)}$$

$$E = \sqrt{25 \text{ volts}}$$

$$E = 5 \text{ volts}$$

Now calculate for current:

$$P = I^2R$$

$$\frac{P}{R} = \frac{I^2R}{R}$$

$$\frac{P}{R} = I^2$$

$$I = \sqrt{\frac{P}{R}}$$

$$I = \frac{\sqrt{25\ (\text{watts})}}{1\ (\Omega)}$$

$$I = \sqrt{25 \text{ amps}}$$

$$I = 5 \text{ amps}$$

With a knowledge of transposition of equations, the solution of a simple circuit can be found when any two values are known. Circuits having known values of power and current, or power and resistance, can be solved like the circuit of figure 2-3 by using Joule's law and Ohm's law correctly. Always begin a circuit analysis by knowing what is given and choosing a formula with two known values and the unknown that you wish to find.

Electrical components are often given a power rating. The power rating in watts indicates the rate at which the device converts electrical energy into another form of energy such as light, heat, or motion. Common examples of devices rated this way are soldering irons and small electric motors.

In some electrical devices the wattage rating indicates the maximum power the device is designed to dissipate, rather than the normal operating power. A 150-watt lamp, for example, dissipates 150 watts when operated at the rated voltage printed on the bulb. In contrast, a device such as a resistor is not normally rated in terms of voltage or current. A resistor is given a power rating in watts and can be operated at any combination of voltage and current as long as the power rating is not exceeded. In most circuits the actual power dissipated by a resistor is considerably less than the resistor's power rating. In well-designed circuits a safety factor of 100 percent or more is allowed between the actual power dissipation of the resistor in the circuit and the power ratIng listed by the manufacturer. The wattage rating listed is the rate at which the resistor can dissipate power without damage from overheating.

Resistors of the same resistance value are available in different wattage values. Carbon resistors, for example, are commonly made in wattage rating of 1/8, 1/4, 1/2, 1, and 2 watts. The larger the physical size of a carbon resistor, the higher its wattage rating, since a larger amount of material radiates heat more easily.

When resistors of wattage ratings greater than 2 watts are needed, wire-wound resistors are normally used. Wire-wound resistors are made in sizes between 5 and 200 watts with special types being used for power in excess of 200 watts.

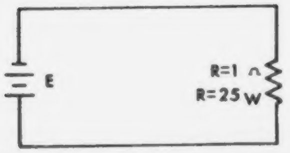

Figure 2–4. Power in a series circuit.

Exercises (412):

1. Using the circuit in figure 2-5, calculate for the unknown values.

2-2. Dividing Voltages

Unlike your home, where practically all electrical appliances operate at the same voltage, avionics systems require several different values of voltage. It is impractical to have a separate power source for each voltage value, especially since some systems require dozens of different voltage values.

413. State the purpose of voltage dividers and state characteristics of voltage divider circuits.

Voltage Dividers. A device that makes it possible to obtain more than one voltage from a single power source is known as a voltage divider. This type of voltage divider is used in many training devices. A simple voltage divider is composed of a number of resistors in series with a power source as shown in figure 2-6. This circuit is simply a series circuit consisting of three resistors connected across a source of voltage. Taps are identified as A, B, C, and D. In addition to taps, a ground reference point has been added to the circuit. The design location of this ground is a very important factor in analyzing the circuit for troubleshooting. You will see why a little later in this section.

With the values shown on figure 2-6, it is easy to see that we have a total resistance of 30 ohms. The applied voltage is 30 volts. By using the Ohm's law (I = E divided by R), we find 1 amp of current will develop a voltage of 5 volts across the 5-ohm resistor, 10 volts across the 10-ohm resistor, and 15 volts across the 15-ohm resistor. The voltage at tap A with respect to ground is 0 volts. The voltage at tap B with respect to ground is 5 volts. The voltage at tap C with respect to ground is 15 volts (5V + 10V). The voltage at tap D with respect to ground is 30 volts (5V + 10V + 15V). Note the voltage at point D is also equal to the applied voltage. Thus, from one common power source it is possible to obtain several different values of voltage.

This voltage divider circuit has one side of the power supply grounded. Now, see what happens when we move the ground from one side of the power supply to some other point in our voltage divider. (see fig. 2-7). By adding resistor values, the total resistance is 200 ohms. With a 100-volt power supply, current will be .5 amps. By using Ohm's law, we find the voltage drops across the resistors to be as follows: R_1 = 20 volts; R_2 = 30 volts; and R_3 = 50 volts.

Since the tap at point A is connected to the negative side of the battery with respect to ground, the voltage at point A is negative 20 volts. Resistors R_2 and R_3 are connected to the positive side of the battery with respect to ground. Thus, the voltages at points C and D will be positive with respect to ground. The voltage drop across R_2 is 30 volts. Since R_2 is connected between point C and ground, the voltage at point C will be positive 30 volts. The voltage at point D will

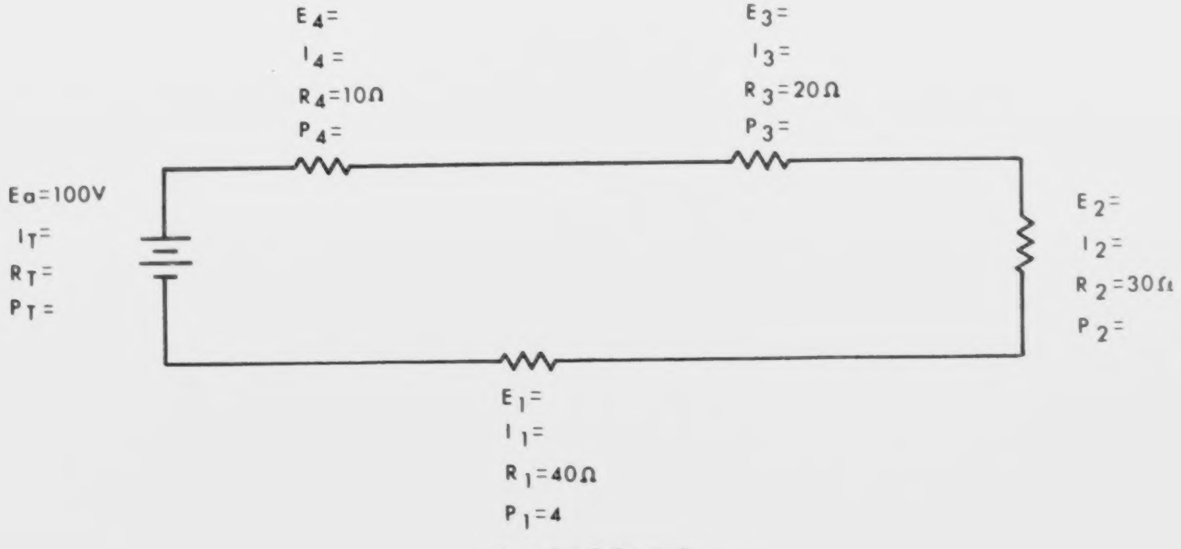

Figure 2–5. Series circuit.

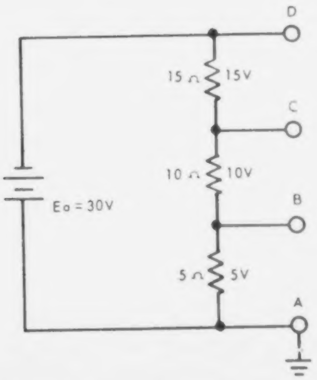

Figure 2-6. Simple voltage divider.

be equal to the voltage drop across R_3 and R_2 or positive 80 volts with respect to ground.

So far we have only concerned ourselves with a ground reference point. Quite often in electronic equipment, the ground symbol not only represents the reference point but it also denotes the metal chassis. Using the metal chassis for ground is valuable when you consider economy, ease of circuit construction, and ease of making electrical measurements. When each electrical circuit is completed, common points are connected directly to the metal chassis; current flows through the metal chassis (conductor) to reach other points of the circuit.

Exercises (413):

1. What is the purpose of the voltage divider?

2. What does the ground symbol used in a voltage divider denote?

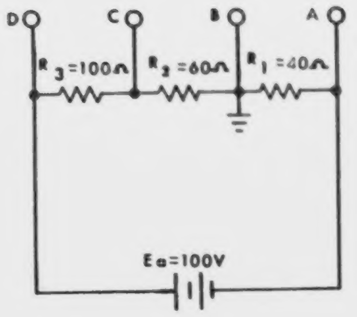

Figure 2-7. Simple voltage divider with a negative potential.

3. With current flowing from a point to ground, what polarity with respect to ground will this voltage have?

4. Using three resistors in a series circuit, with a power source, how many different voltages can be supplied to different loads?

414. State the purpose of rheostats and potentiometers in electrical circuits and the number of active terminals in each.

Rheostats and Potentiometers. In our study of voltage dividers we used fixed resistors in the circuit. Quite often a voltage divider network will use a variable resistor—either a rheostat or a potentiometer. Rheostats have two connections, one for the fixed resistance element and one for the variable wiper arm. Generally, the rheostat has a limited range of values and a high current-handling capability. The potentiometer has a wide range of values, but is has a limited current-handling capability.

Rheostats. A rheostat is a variable resistor that may be used as a control to vary the amount of current that flows through a voltage divider. A typical circuit using a rheostat is shown in figure 2-8. Since the rheostat controls the current, it will determine the voltage drop between point X and ground. Examine the figure to see how the rheostat works. As the slider arm is moved from A toward B, the amount of rheostat resistance in the circuit is increased. Since the rheostat resistance and the fixed resistance are in series, the total resistance of the circuit also increases. The total current in the circuit, therefore, decreases. As the slider arm is moved toward A, the total resistance decreases and current increases.

Potentiometers. A potentiometer is a control used to vary the amount of voltage applied to an electrical device or circuit (see fig. 2-9). Examine the figure to see how the potentiometer works. As the slider arm of R_2 is moved from A to B or B to A, neither the amount of resistance nor the current will change. However, if a voltmeter is connected in the circuit, as shown, a change in voltage is noted as the arm is moved.

Using a potentiometer in a voltage divider network lets us obtain a variable voltage from a fixed voltage source. The potentiometer is one of the most common controls found in

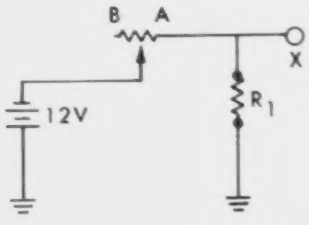

Figure 2-8. Rheostat as a voltage divider.

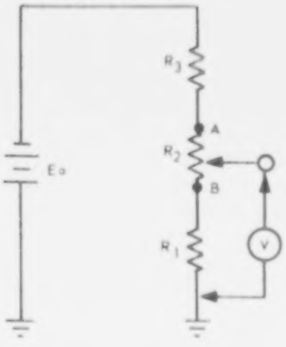

Figure 2–9. Potentiometer as voltage divider.

electronic applications. In choosing a potentiometer for a given purpose, follow the same rules as for a resistor. Select the proper ohmic value and power rating.

Exercises (414):

1. What is the purpose of a rheostat?

2. How many active terminals does a rheostat have?

3. How many active terminals does a potentiometer have?

4. What is the purpose of a potentiometer?

2-3. Calculating and Troubleshooting

In this section we will discuss calculating and troubleshooting DC parallel and series-parallel resistive circuits.

415. Calculate voltages, currents, resistances, and power in DC parallel circuits.

Calculating Parallel Resistive Circuits. It is often necessary to connect electrical devices so the entire source of voltage is across each device. A circuit in which two or more devices are connected across the same voltage source is a parallel circuit. Now refer to the circuit in figure 2-10. Note that points A, B, C, and D are connected together and are one point electrically when the circuit is closed as shown. Similarly points E, F, G, and H comprise another electrical point. Since the applied voltage appears between points A and E, the same voltage appears between points B and F, between points C and G, as well as between points D and H. So it can be said that resistors connected in parallel across a voltage source all have the same voltage applied, although the currents may differ depending on the values of resistance. Let's discuss these points more thoroughly.

Calculating voltage. Kirchhoff's law states that the sum of the voltage drops in a closed loop equals the applied voltage. Let's prove this by calculating the voltage drop across each of the resistors in figure 2-10. In the circuit shown, resistors R_1, R_2, and R_3 form three parallel closed loops with 30 volts applied. If we find the voltage drop across any one of the resistors, we should have the applied voltage. Let's calculate the voltage drop of R_1 by using Ohm's law and the indicated value of resistance and branch current:

$$E_{R1} = I_1 R_1$$

$$E_{R1} = 2\text{A} \times 15\ \Omega$$

$$E_{R1} = 30 \text{ volts}$$

Now, by using the same form of Ohm's law and the indicated branch values of current and resistance, we will calculate the voltage drops of R_2 and R_3:

$$E_{R2} = I_2 R_2$$

$$E_{R2} = 1\text{A} \times 30\Omega$$

$$E_{R2} = 30\text{volts}$$

$$E_{R3} = I_3 R_3$$

$$E_{R3} = 1.5\text{A} \times 20\Omega$$

$$E_{R3} = 30 \text{ volts}$$

$$E_a = E_{R1} = E_{R2} = E_{R3}$$

We have now proved that voltage drops across each resistor or branch loops are equal to the applied voltage.

Calculating current. The division of total current among the branches in a parallel circuit depends on the resistance of each branch. Branches in a parallel circuit with low resistance draw more current than branches with high resistance. The current flow in the circuit may be expressed mathematically:

$$I_t = I_1 + I_2 + I_3$$

Thus, to calulate the total current, simply add up the individual branch currents with Ohm's law. This is done by

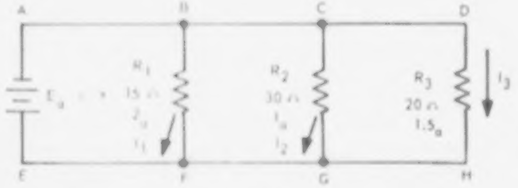

Figure 2–10. Voltage in a parallel circuit.

dividing the applied voltage by the resistance of the individual resistors.

Calculating resistance. The total resistance of any number of equal resistors connected in parallel is equal to the resistance of one resistor divided by the number of resistors. Expressed mathematically:

$$R_t = \frac{R}{N}$$

Where R_t is the total resistance, R is the resistance of one resistor, and N is the number of resistors.

The equivalent resistance of any two resistors in parallel is equal to the product of the two resistors divided by their sum:

$$R_t = \frac{R_1 R_2}{R_1 + R_2}$$

For example, if a circuit has a 20-ohm and a 30-ohm resistor in parallel their equivalent resistance is:

$$R_t = \frac{20 \times 30}{20 + 30} = \frac{600}{50} = 12 \text{ ohms}$$

Now let's discuss a little more difficult circuit having more than two unequal resistors in parallel. Using the circuit in figure 2-12, let's solve for individual branch resistances, by Kirchhoff's law, we know that the voltage drop across each resistor is equal to the applied voltage. By using Ohm's law, the resistance of each branch can be calculated:

$$\begin{aligned} R1 &= \frac{E_a}{I_1} \\ &= \frac{28V}{2a} \\ &= 14 \text{ ohms} \end{aligned}$$

$$\begin{aligned} R_2 &= \frac{E_a}{I_2} \\ &= \frac{28V}{.5a} \\ &= 56 \text{ ohms} \end{aligned}$$

$$\begin{aligned} R_3 &= \frac{E_a}{I_3} \\ &= \frac{28V}{1a} \\ &= 28 \text{ ohms} \end{aligned}$$

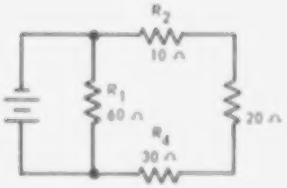

Figure 2-11. Parallel circuit (more than one resistor in a branch).

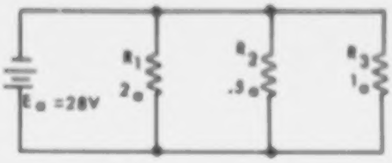

Figure 2-12. Parallel circuit (individual branch resistance).

Since the resistors are of unequal value and the circuit contains more than two parallel resistors, we must use the following general formula to solve for total resistance:

$$\frac{1}{R_t} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \ldots$$

This reciprocal formula can be rewritten as:

$$R_t = \frac{1}{\frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}}$$

Then by substituting our calculated values:

$$\begin{aligned} R_t &= \frac{1}{\frac{1}{14} + \frac{1}{56} + \frac{1}{28}} \\ &= \frac{1}{.125} \\ &= 8 \text{ ohms} \end{aligned}$$

Calculating power. Using the circuit in figure 2-12, let's determine the power dissipated by the circuit. When we are given the voltage and the individual branch currents, the power formula can be used in this form: P = IE. The power dissipated by each resistor is equal to the current flowing through it times the voltage drop across it. Thus, the power dissipated by the three resistors is:

$P_{R1} = 56$ watts

$P_{R2} = 14$ watts

$P_{R3} = 28$ watts

The total power P_t dissipated by any circuit is always equal to the sum of the power dissipated by the individual resistors. Thus, P_t for the circuit shown in figure 2-12 is 98 watts.

The total power dissipated by the circuit in fugure 2-12 can also be calculated by multilying total current times the applied voltage.

$$P_t = I_t E_a$$

The power formula has two other forms. For example, if the total current and total resistance are known (but the voltage unknown), we can use:

$$P_t = I_t^2 R_t$$

If the applied voltage and the total resistance are known we can use this form of the basic formula:

$$P_t = \frac{E^2}{R_t}$$

Exercises (415):

1. Using the circuit in figure 2-13, calculate for the unknown values.

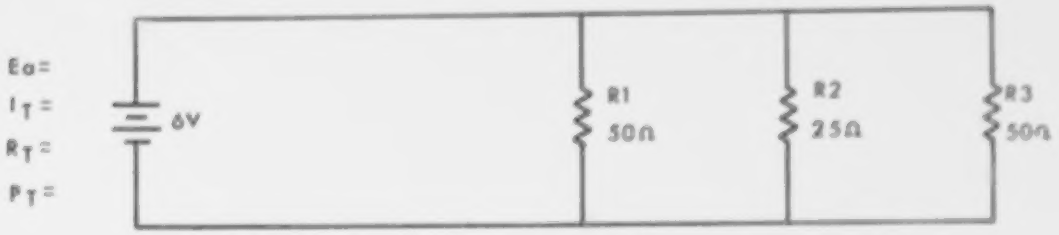

Figure 2-13. Parallel circuit.

416. Solve hypothetical problems in parallel DC circuits.

Troubleshooting Parallel Resistive Circuits. Troubleshooting parallel circuits follows the same applied practical techniques you use in troubleshooting almost any electrical circuit. Use the ammeter-voltmeter-ohmmeter functions of our multimeter to help you in locating a defective component. The only difference in troubleshooting a parallel circuit when compared with a series circuit is the way you apply the techniques of troubleshooting. For example, if a component in a series circuit is open, no circuit current is indicated. This indication is not true with respect to a parallel circuit. If a component in a parallel circuit is open, there will be a decrease in circuit current.

In the parallel circuit shown in figure 2-14, let's examine the effect an open resistor has on circuit operation. For ease of explanation we have used three resistors of equal size. Let's assume that resistor R_3 is open. Unlike a series circuit, current continues to flow through the good components in a parallel circuit. However, current ceases to flow through the open component. Also unlike the series circuit, an open component in this type of circuit cannot be detected with a voltmeter. The quickest way to detect an open component or resistor in this case is with the use of an ammeter or ohmmeter. Before going any further let's calculate the total resistance, total current, and individual branch currents when the circuit is trouble-free. Using methods discussed in the previous section, you will find that the total resistance is 10 ohms and the total current flow is 3 amps.

Now that we know what the total current and branch currents are supposed to be, let's insert an ammeter into the circuit as shown in figure 2-14. At this point in the circuit, the ammeter should read the total current, 3 amps. However, let's assume that the meter reads 2 amps. Since we know the branch current is supposed to be 1 amp in each branch, it is obvious that one branch must be open. Thus, we should insert an ammeter into each branch at a point just below the resistor. The branch showing zero current flow is open.

Another way to locate this same trouble is with the use of an ohmmeter. If, after disconnecting the power source, an ohmmeter is connected across R_3, as shown in figure 2-15, we would obtain a reading which would be misleading. Although R_3 is open, the ohmmeter will still measure the resistance of R_1 and R_2 in parallel. Two 30-ohm resistors in parallel would give us an equivalent resistance of 15 ohms.

To determine accurately the condition of R_3 with an ohmmeter, we must disconnect the defective component from the remaining circuits. In this manner the resistor being checked, R_3 in our case, is not shunted or paralleled by R_1 and R_2. As we have previously stated, R_3 is open; thus the reading on the ohmmeter would indicate an infinite resistance.

In a series circuit, a voltmeter is often used as an aid in locating a defective component such as an open resistor. A voltmeter reads the applied voltage when it is placed across an open circuit. This technique cannot be followed in troubleshooting a simple parallel circuit. Refer to figure 2-15. We know that resistor R_3 is open. If we place a voltmeter across R_3, it would read the applied voltage of 30V. If we place a voltmeter across R_1 and R_2, it would also read the applied voltage. When a voltmeter is placed across a good component or an open component in a simple parallel circuit, the voltmeter still reads the applied voltage. It follows then that, in troubleshooting a parallel circuit, you should not rely on a voltmeter to locate a defective component.

This far, we have been discussing troubleshooting parallel circuits with respect to open components. Let's see what effect a shorted component has on a parallel circuit. Assume R_3 is shorted. This condition would present the current a path of negligible resistance. Since current always takes the path of least resistance, the total current would flow through the short.

Another way to look at the circuit with R_3 shorted is just like connecting the two terminals of the 30-volt battery together. In either case, current rises to an excessive value and the fuse would burn out. Once the fuse has blown, the

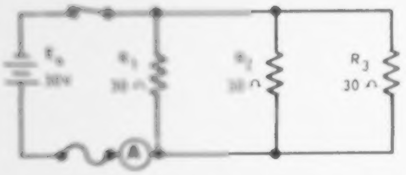

Figure 2-14. Parallel circuit (troubleshooting).

current total circuit current ceases to flow and the applied voltage would no longer be felt across R_1 or R_2.

Since a shorted component usually means a blown fuse, troubleshooting with an ammeter or voltmeter becomes difficult. However, we still have the ohmmeter as an aid in locating the defective component. As in the case of troubleshooting for an open resistor in a parallel circuit, a shorted resistor can be detected with an ohmmeter only if one end is disconnected. A shorted resistor will give a reading of 0 ohms on the ohmmeter.

Exercises (416):

1. In troubleshooting a resistive parallel DC circuit, you find the current has decreased. What would be a probable cause?

2. In troubleshooting the circuit in exercise 1, what reading will you get when you place an ammeter in the branch containing the open resistor?

3. Why must a defective component be disconnected from the remaining circuit when using an ohmmeter to determine its condition?

4. In a parallel circuit that contains three branch resistors, if one resistor suddenly shorts, how are circuit operations affected?

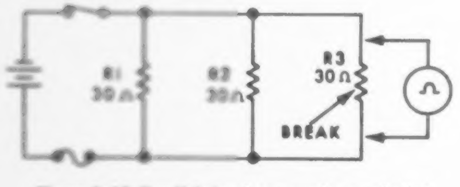

Figure 2-15. Parallel circuit (measuring continuity).

417. Calculate values for resistance, current, and voltage in a series-parallel circuit.

Series-Parallel Resistive Circuits. A series-parallel circuit appears to be very complex for a beginner in electronics. However, by applying the same laws and using the same rules as we have learned from series circuits and parallel circuits, series-parallel circuits will not be as complex as they appear. A series-parallel circuit consists of groups of parallel resistance in series with other resistances. An example of a series-parallel circuit is shown in figure 2-16,A.

Perhaps the easiest method of working with series-parallel circuits is to break them down and redraw them as equivalent series circuits. The first step in redrawing the circuit is to reduce the two parallel resistances, R_2 and R_3, to an equivalent single resistance. We will call this single equivalent resistance R_4. We can solve for R_4 by using the "product over the sum" formula.

$$R_4 = \frac{R_2 R_3}{R_2 + R_3}$$

$$R_4 = \frac{10 \times 10}{10 + 10}$$

$$R_4 = 5 \text{ ohms}$$

Thus, in place of the two 10-ohm resistors, we could insert into the circuit a single 5-ohm resistor without altering the total current in the circuit. At this time we can also redraw the circuit to appear as shown in figure 2-16,B. Since the total resistance of the circuit is equal to R_1 plus R_4, or 10 ohms, we can calculate the total current with Ohm's law.

$$I_t = \frac{E_a}{R_t}$$

$$= \frac{10V}{10\Omega}$$

$$= 1 \text{ amp}$$

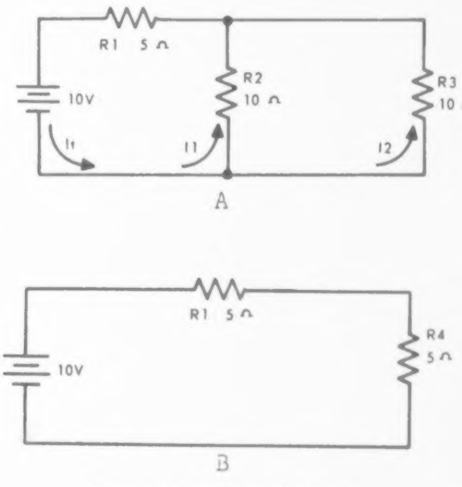

Figure 2–16. Series-parallel circuits.

This 1 amp of current is the total current of the circuit. Thus, the voltage drop across each resistor is 5 volts. The voltage drop across both resistors is 10 volts. The individual powers dissipated by each resistor and the total power can now be calculated with any convenient power formula we have studied.

Let's take another series-parallel circuit, such as shown in figure 2-17,A, and find the simple series equivalent circuit, total resistance, total current, branch currents, individual voltage drops, and total power dissipated by the circuit.

To begin, add the series resistance R_3 and R_4 to get the equivalent resistance R_5 that is equal to 20 ohms as shown in figure 2-17,B. R_2 and R_5 are in parallel and of equal value, 20 ohms each. Thus, their total is 10 ohms. If R_2 and R_5 are replaced by a series 10-ohm resistor, the circuit will appear as a simple series circuit with a total resistance of 20 ohms. The total current flow, then, is 3 amps and the voltage drop across R_1 is 30 volts. Thus, the voltage drop from point A to B is 30 volts. Refer to figure 2-17,B, and you will see that total current flows through R_1. Knowing the current through R_1, you can calculate the voltage drop across R_1.

Now let's go back to figure 2-17,A. We know the voltage across the parallel network, point A to point B is 30 volts. This 30 volts is across R_2 and the series combination (R_5) of R_3 and R_4. Knowing the voltage across each branch in the network, you can now calculate branch currents by using Ohm's law formula for each resistor:

$$I = \frac{E}{R}$$

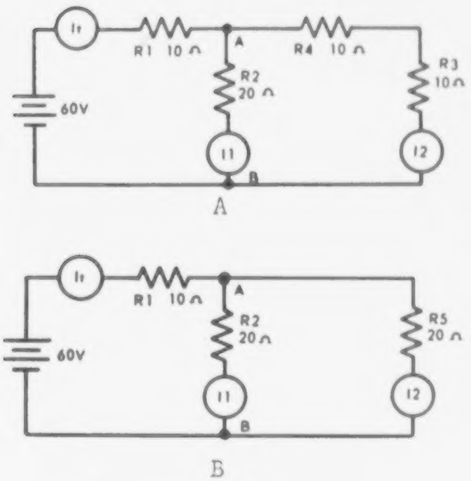

Figure 2–17. Series-parallel circuits.

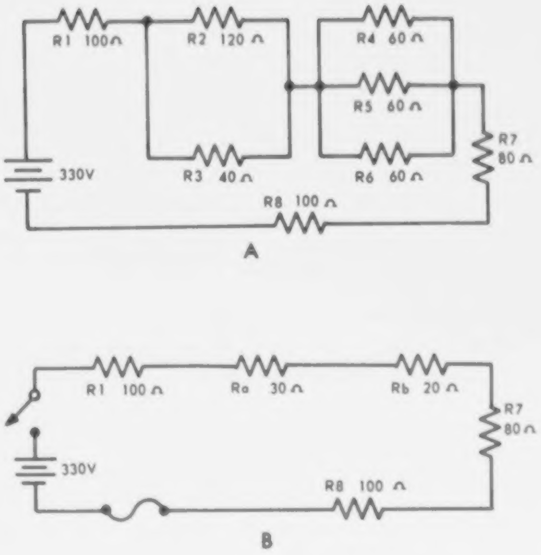

Figure 2–18. Complex series-parallel circuits.

Your calculations should show that the current flow through each branch is 1.5 amps, or a total current flow of 3 amps. You can determine total power dissipated by the circuit in figure 2-17 by using the power formula P = IE.

Let's take the series-parallel circuit shown in figure 2-18 and find the simple series equivalent circuit and total resistance. The first thing to be done with the circuit is to reduce each group of parallel resistors to a single equivalent resistor. The first parallel group is R_2 and R_3. Use the formula:

$$R_2 = \frac{R_2R_2}{R_2 + E_3}$$

You will find the equivalent resistance is 30 ohms.

The next step is to find the equivalent resistance of the parallel combination of R_4, R_5, and R_6. Since all are of equal value the total is 20 ohms. The two parallel combinations can be redrawn as single 30-ohm and 20-ohm resistors as shown figure 2-18,B. Now, we have an equivalent series circuit in which the total resistance can be found very easily by adding all the resistance values. Your calculation should show that the total resistance is 330 ohms.

Now with total resistance and applied voltage known, it is simple to determine that the circuit current flow is 1 amp. Voltage drop across each resistor is found with the formula E = IR. Power dissipated by each resistor can be found with the formula P = IE.

Exercises (417):

Ea =

RT =

IT =

PT =

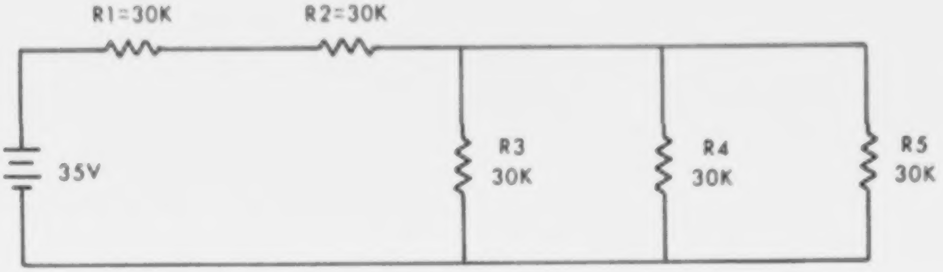

Figure 2-19. Series-parallel circuit.

1. Using the circuit in figure 2-19, calculate the unknown values.

418. State how to troubleshoot shorts and opens in series-parallel circuits.

Troubleshooting Series-Parallel Circuits. Troubleshooting a series-parallel resistive circuit is quite similar to troubleshooting a series or parallel-resistive circuit. Two troubles you will encounter in a series-parallel circuit are our old enemies—the open and the short. First, let's see what effect an open has on a series-parallel circuit by using figure 2-20.

Circuit analysis. Assume that an open occurs in the series portion (R_1) of the circuit, current flow in the entire circuit will stop. In this case the entire circuit will cease to function. If an open occurs in either of the parallel branches (R_2 or R_3) of the circuit, the remaining portion of the circuit will continue to function. Analyzing the circuit tells us that with either (but not both) parallel resistor open, the circuit becomes a simple series circuit. With either parallel resistor open, total resistance increases and total current decreases. A decrease in total current results in a decrease in voltage drop across (R_1). If the voltage drop across R_1 decreases, then by Kirchhoff's law the voltage drop across the remaining good parallel resistor must have increased. If an open occurs in R_3, current through the series portion of the circuit will continue to flow, causing an increase in voltage across R_2.

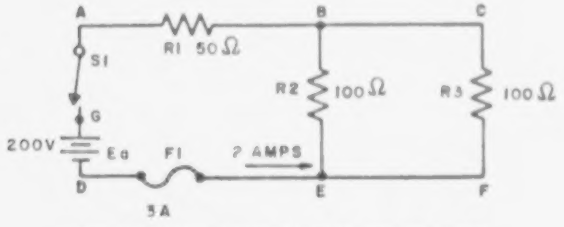

Figure 2-20. Series-parallel circuits (troubleshooting).

A short in the series portion of a series-parallel circuit will cause a decrease in total resistance. This, in turn, will cause the total current to increase. Let's again examine the circuit as shown in figure 2-20.

Since R_1 is 50 ohms and the equivalent resistance of R_2 and R_3 is 50 ohms, the total resistance is 100 ohms. The total current is 2 amps. If R_1 became shorted the total resistance would decrease 50 ohms and the total current would increase to 4 amps. This increase in current would be sufficient to blow the 3 amp fuse. The same thing would occur in the circuit if either R_2 or R_3 became shorted. The total resistance in the circuit would be 50 ohms, the value of the series resistor only.

Troubleshooting with a voltmeter. Another way to troubleshoot a circuit is with a voltmeter or ohmmeter. However, troubleshooting series-parallel circuits with a voltmeter can be very difficult unless you have some knowns as references. If you know component sizes and the applied voltage, a little mathematical computation will let you troubleshoot with accuracy.

To troubleshoot the circuit in figure 2-20, you must make certain assumptions. The first assumption is that all components are good, except the one being checked. These are some indications you can expect when the voltmeter is placed across each component. For example, with the voltmeter across an open switch you will read the applied voltage. If the switch is shorted, you will read zero volts on the voltmeter. Likewise if the switch is good, you will read zero volts. However, a reading across an open series resistor will give you the applied voltage reading.

Like an open, a short can be detected with a voltmeter. Let's examine the circuit again in figure 2-20. Placing the voltmeter across points A and B would indicate the condition of R_1. If R_1 is shorted no voltage would be indicated between these points. If R_1 is good then the voltage drop of R_1 would be read. You can get an indication of a short in the parallel portion of the circuit, but you can't isolate the defective branch. By connecting the voltmeter across points B and E, the parallel combination can be checked. If one of the resistors in the parallel combination is shorted, the reading between points B and E and points C and F will be zero. To determine which resistor is shorted, disconnect either R_2 or R_3 from the circuit and check it with an ohmmeter.

Troubleshooting with an ohmmeter. This can be done much the same as it is with a voltmeter. Remember, though, whenever you troubleshoot with an ohmmeter, the power must first be removed from the circuit. Let's again refer to figure 2-20 and assume that switch S_1 is open to remove the source voltage from the circuit. By placing the meter across points A and B, you can check the circuit between these points for continuity. If resistor R_1 is open, the meter will read infinite resistance. If it is good, the value of the resistor will be indicated on the meter.

Like the voltmeter, the ohmmeter can give misleading indications in the parallel portion of the circuit. In order to check the circuit between points B and E, one of these points will have to be broken (disconnected).

Troubleshooting for a short with the ohmmeter is the same as troubleshooting an open. The only difference is the reading obtained on the meter. When the ohmmeter is connected across a shorted component, the reading will be zero.

Exercises (418):

1. How is current flow affected if an open occurs in the series portion of a series-parallel circuit?

2. How is current flow affected if a short occurs in the series portion of a series-parallel circuit?

3. If an open occurs in the parallel portion of a series-parallel circuit, how is the voltage drop across the series resistor affected?

4. If a short occurs in the parallel portion of a series-parallel circuit, how is total resistance affected?

5. If a voltmeter is connected across a good series resistor in a series-parallel circuit, what will the reading be?

6. What precautionary step must you take before connecting an ohmmeter into an electrical circuit?

7. What is the meter reading on an ohmmeter connected across a shorted component?

2-4. Voltage Dividers and Bridge Circuits

In this section we will be discussing loaded voltage dividers and calculating resistance, current, and voltage of loaded voltage dividers. We will also discuss resistive bridge circuits.

419. Calculate values for resistance, current, and voltage in loaded voltage dividers, and state characteristics of a loaded voltage divider circuit.

Loaded Voltage Dividers. In an earlier section of this chapter, you learned that the voltage divider resembles a simple series circuit. Its purpose is to provide voltage values other than the source voltage. We will now discuss what happens when load devices are connected to the simple voltage divider.

A load device is any component, mechanical or electrical, that consumes power as it performs its function. A resistor is often used as a load device. We must distinguish between the terms "load device" and "load." Load means current. When we speak of a light load or a heavy load, we refer to the amount of current being drawn from the power source or battery. It stands to reason, then, that the ohmic value of the load device will determine the amount of load placed on a given voltage source. By placing the load device across a voltage divider, we now have a loaded voltage divider circuit.

Figure 2-21 illustrates a loaded voltage divider circuit with four different load devices: R_5 between point D and ground; R_6 between point C and ground; R_7 between point B and ground; and R_8 between point A and ground. Careful inspection of this loaded voltage divider circuit shows it to be a complex series-parallel circuit.

To calculate the current and the voltage drops within a voltage divider, use Kirchhoff's laws. The current law states that the sum of the currents entering any point in a circuit will equal the sum of the currents leaving that point. The voltage law states that the sum of the voltage drops around a closed loop will be equal to the applied voltage. Keep these laws in mind while you work with voltage dividers. The current drawn from the power source divides between the voltage divider and load devices; it unites again as it returns to the power source. The voltage divider, with the power supply, forms a closed loop, and the sum of the voltage drops along the divider will equal the applied voltage. The voltage across the various load devices will equal the voltage present at the tap on the divider. As shown in figure 2-21, the voltage dropped across R_4 is the voltage present at point D with respect to ground. Now let's use the voltage divider circuit shown in figure 2-21 and solve for total resistance, total current, and voltage at each point.

Solving for resistance. The combined effect of the individual load resistors and the voltage divider resistors in the circuit can be solved if you start at the inside of the circuit and work out. We will use equivalent circuits shown in figure 2-22 for our discussion. Refer to the corresponding figure identified by step numbers to review each of the following steps in computing the resistance.

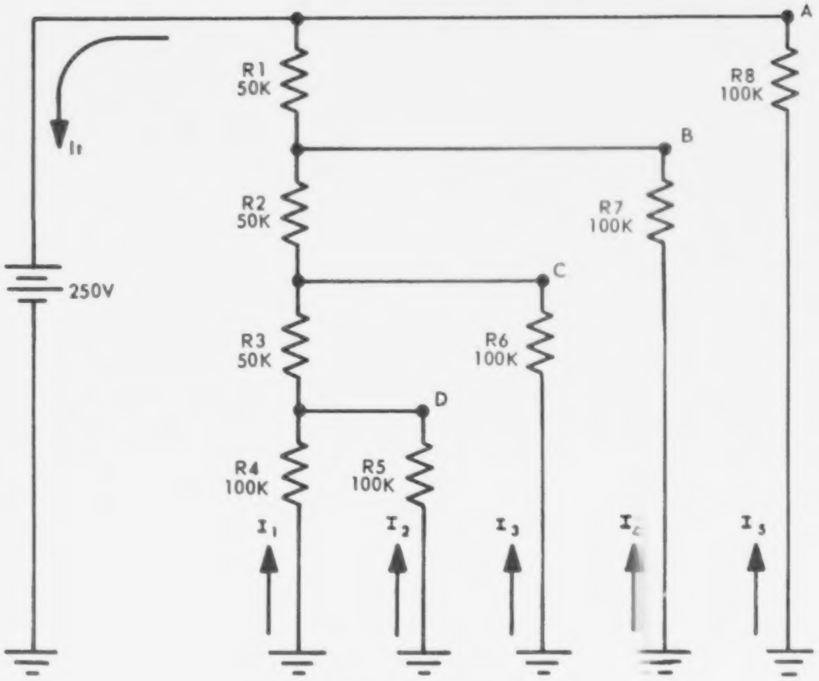

Figure 2–21. Voltage divider (solving for voltage).

Step 1:

$$R_{e1} = \frac{R_4 \times R_5}{R_4 + R_5}$$

NOTE: R_{e1} is defined as "resistance equivalent 1."

$$= \frac{100k \times 100k}{100k + 100k}$$

$$= 50k\Omega$$

Step 2:

$$R_{e2} = \frac{(R_{e1} + R_3) \times R_6}{(R_{e1} + R_3) + R_6}$$

$$= \frac{(50k + 50k) \times 100k}{(50k + 50k) + 100k}$$

$$= 50\Omega$$

Step 3:

$$R_{e3} = \frac{(R_{e2} + R_2) \times R_7}{(R_{e2} + R_2) + R_7}$$

$$= \frac{(50k + 50k) \times 100k}{(50k + 50k) + 100k}$$

$$= 50\Omega$$

Step 4:

$$R_t = \frac{(R_{e3} + R_1) \times R_8}{(R_{e3} + R_1) + R_8}$$

$$= \frac{(50k + 50k) \times 100k}{(50k + 50k) + 100k}$$

$$= 50k\Omega$$

Solving for current and voltage. With the total resistance of 50k Ω known, the load (total current) placed on the voltage source by the divider can be calculated by the following Ohm's law formula:

$$I_t = \frac{E_A}{R_t} = \frac{250V}{50k} = \frac{250V}{50 \times 10^3}$$

$$= 5 \times 10^{-3} \text{ amps}$$

$$= 5mA$$

With the total current known, we can apply Kirchhoff's law and Ohm's law to solve for individual branch currents and the voltage at each point along the divider with respect to ground. Figure 2-23 shows the individual paths of current through the divider circuit. The total current in the circuit is equal to the sum of the individual branch currents or

$$I_t = I_1 + I_2 + I_3 + I_4 + I_5$$

The current through R_1, identified as I_{R_1}, is equal to $I_t - I_5$.

In the same manner

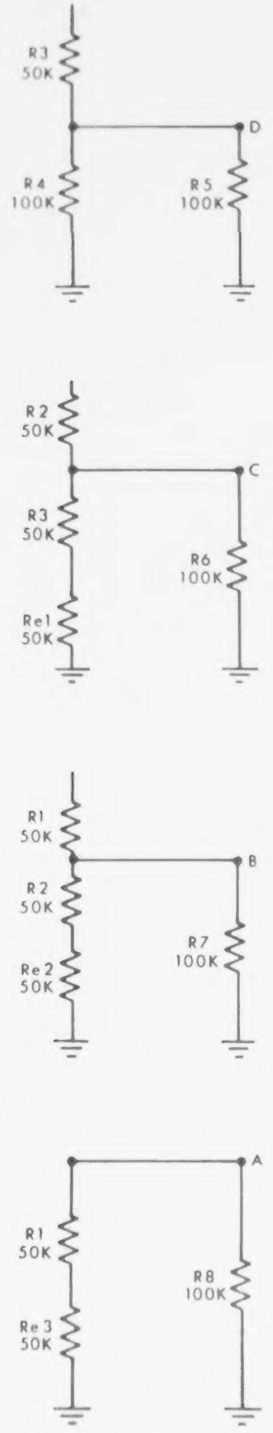

Figure 2-22. Solving for resistance.

$$I_{R2} = I_t - (I_4 + I_5)$$

$$I_{R3} = I_t - (I_3 + I_4 + I_5)$$

$$I_{T4} = I_t - (I_2 + I_3 + I_4 + I_5)$$

When determining network resistance we worked from the inside. Now, to determine voltages and branch currents, let's start with the outermost load device in figure 2-23. The voltage across resistor R_8 (point A with respect to ground) is the source voltage. We can, therefore, use Ohm's law to find the current through R_8. The following steps are shown in progressive order as a method of determining the voltage at each point along the divider and the individual branch currents. Use figures 2-23 and 2-24 as an aid.

Step 1:

$$E_A = \text{source voltage } E_a\text{, 250V}$$

$$I_5 = \frac{E_A}{R_8} = \frac{250\text{V}}{100\text{k}\Omega} = 2.5\text{ mA}$$

Step 2:

$$I_{R_1} = I_t - I_5 = 5\text{mA} - 2.5\text{mA} = 2.5$$

$$E_{R_1} = I_{R_1} R_1$$

$$= 2.5\text{mA} \times 50\text{k}\Omega$$

$$= 125\text{V}$$

$$E_B = E_A - E_{R_1}$$

$$= 250\text{V} - 125\text{V} = 125\text{V}$$

$$I_4 = \frac{E_B}{R_7} = \frac{125\text{V}}{100\text{k}\Omega} = 1.25\text{mA}$$

Step 3:

$$I_{R_2} = I_t - (I_4 + I_5)$$

$$= 5\text{mA} - (1.25\text{mA} + 2.5\text{mA})$$

$$= 1.25\text{mA}$$

$$E_{R_2} = I_{R_2} R_2$$

$$= 1.25\text{mA} \times 50\text{k}\Omega = 62.5\text{V}$$

$$E_c = E_A - (E_{R_1} + E_{R_2})$$

$$= 250\text{V} - (125\text{V} + 62.5\text{V})$$

$$= 62.5\text{V}$$

$$I_3 = \frac{E_C}{R_6} = \frac{62.5\text{V}}{100\text{k}\Omega} = .625\text{mA}$$

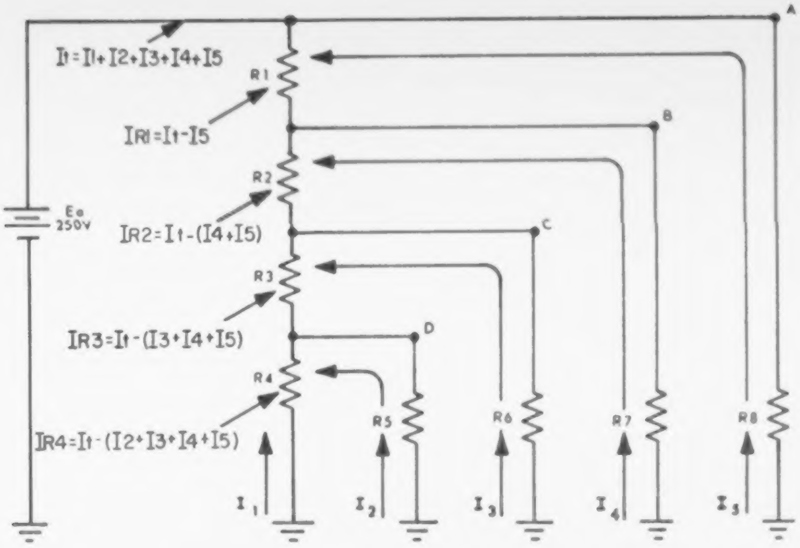
A
It=I1+I2+I3+I4+I5
R1
IR1=It-I5
B
R2
Ea
250V
IR2=It-(I4+I5)
C
R3
IR3=It-(I3+I4+I5)
D
R4
IR4=It-(I2+I3+I4+I5)
R5
R6
R7
R8
I1
I2
I3
I4
I5

Figure 2–23. Voltage divider (individual paths of current flow).

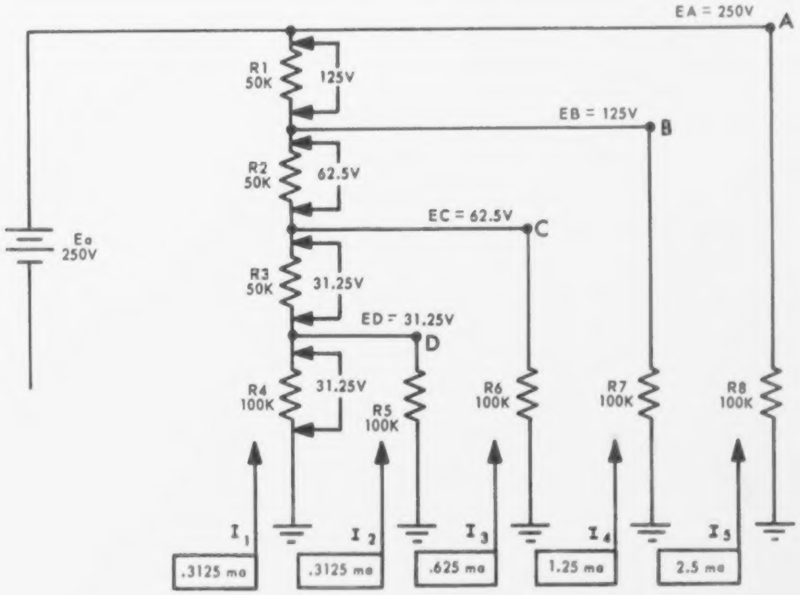
EA = 250V
A
R1
50K
125V
EB = 125V
B
R2
50K
62.5V
EC = 62.5V
C
Ea
250V
R3
50K
31.25V
ED = 31.25V
D
R4
100K
31.25V
R5
100K
R6
100K
R7
100K
R8
100K
I1
.3125 ma
I2
.3125 ma
I3
.625 ma
I4
1.25 ma
I5
2.5 ma

Figure 2–24. Voltage divider (solving for individual currents).

Step 4:

$$I_{R_3} = I_t - (I_3 + I_4 + I_5)$$
$$= 5\text{mA} - (.625\text{mA} + 1.25\text{mA} + 2.5\text{mA})$$
$$= .625\text{mA}$$
$$I_{R_3} = I_{R_3} R_3 = .625\text{mA} \times 50\text{k}\Omega = 31.25\text{V}$$
$$E_D = E_A - (E_{R_1} + R_{R_2} + E_{R_3})$$
$$= 250\text{V} - (125\text{V} + 62.5\text{V} + 31.25\text{V})$$
$$= 31.25\text{V}$$
$$I_2 = \frac{E_D}{R_5} = \frac{31.25\text{V}}{100\text{k}\Omega} = .3125\text{mA}$$
$$I_1 = \frac{E_D}{R_4} = \frac{31.25\text{V}}{100\text{k}\Omega} = .3125\text{mA}$$

Now analyze the voltage divider circuit shown in figure 2-25. The load resistor R_3 is connected through switch S1 to point Y on the voltage divider. First, we will calculate the voltage at point Y with the switch open under a no-load condition. Second, we will calculate the voltage at point Y under a loaded condition with the switch closed.

Switch open:

$$R_t = R_1 + R_2 = 30\text{k} + 30\text{k} = 60\text{k}\Omega$$
$$I_t = \frac{E_a}{R_t} = \frac{120\text{V}}{60\text{k}}\Omega = 2\text{mA}$$
$$E_{R_1} = I_t \times R_1 = 2\text{mA} \times 30\text{k}\Omega = 60\text{V}$$
$$E_{R_2} = E_a - E_{R_1} = 120\text{V} - 60\text{V} = 60\text{V}$$
$$E_Y = E_{R_2} = 60\text{V}$$

The voltage at point Y without the load device connected to the divider is 60 volts. Total resistance of the circuit is 60k Ω and total current is 2 mA.

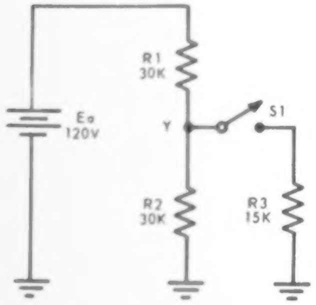

Figure 2-25. Voltage divider (calculating voltage under load and no load conditions).

Switch closed:

$$R_e = \frac{R_2 \times R_3}{R_2 + R_3} = \frac{30\text{K}\Omega \times 15\text{K}\Omega}{30\text{K}\Omega + 15\text{K}\Omega} = 10\text{K}\Omega$$
$$R_t = R_1 + R_e = 30\text{K}\Omega + 10\text{K}\Omega = 40\text{K}\Omega$$
$$I_t = \frac{E_a}{R_t} = \frac{120\text{V}}{40\text{K}\Omega} = 3\text{mA}$$
$$E_{R_1} = I_t \times R_1 = 3\text{mA} \times 30\text{K}\Omega = 90\text{V}$$
$$E_{R_2} = E_{R_3} = E_a - E_{R_1} = 120\text{V} - 90\text{V} = 30\text{V}$$
$$E_Y = E_{R_2} = E_{R_3} = 30\text{V}$$

The voltage at point Y with the load device connected to the divider is 30 volts. Total resistance of the circuit is 40k Ω and total current is 3 mA. Looking back over our calculations, we can make the following conclusions concerning a load device connected to a voltage divider:

a. Total circuit resistance decreases.

b. Total circuit current increases; that is, the load on the voltage portion of the divider decreases.

c. The voltage drop across the loaded portion of the divider decreases.

d. Voltage drop across the series resistor increases.

All voltages obtained in the previous explanations have been positive in polarity. In every case, the negative terminal of the battery is grounded. This makes all other points in the circuit positive with reference to ground. Recall that voltage dividers can supply negative voltages when the positive battery terminal is grounded. With the most positive point grounded, all other points in the circuit are negative with reference to that point.

When you studied unloaded voltage dividers, we learned that both positive and negative voltages may be obtained from a single voltage divider. This happens if some point of the resistive network is grounded. This point could NOT be one of the battery terminals, but must be in the resistance network of the voltage divider. Calculations for these circuits are the same as for the examples shown. Just keep in mind that ground is merely a reference point.

Exercises (419):

1. What is meant by a loaded voltage divider?

2. How many paths are there for current flow in a loaded voltage divider?

3. What does the term "load" mean?

4. What is the polarity of the ground reference point in a voltage divider?

5. When a load device is placed across a voltage divider, what happens to total circuit resistance, total circuit current, and the voltage drop across the series resistor?

6. Using the circuit in figure 2-26, calculate the unknown values.

420. State what conditions exist in balanced and unbalanced resistive bridge circuits.

Resistive Bridge Circuits. Bridge circuits are frequently used in electronics where a signal from one "detecting" device is used to drive or correct another operational device. Some bridge circuits have fixed components, while others have adjustable components. With a variable component, a bridge circuit is very accurate test equipment.

Figure 2-27,A, shows a regular parallel circuit with which we are already familiar. It has two paths for current flow. Note we have inserted two identifying points on the circuit, point A between resistors R_1 and R_2 and point B between resistors R_3 and R_4. Suppose we take points A and B and stretch the circuit. The result is a diamond shape. To make a bridge circuit out of this diamond shape, some type of resistive load (the detecting device) must be connected between points A and B as shown in figure 2-27,B.

Balanced bridge circuits. Perhaps you can see a relationship in the circuit already. If there is a difference of potential between points A and B of the bridge circuit, current will flow through the load device (R). The direction of current flow is determined by the polarity of voltage present at point A with respect to point B. On the other hand, if there is no difference of potential between points A and B, no current will flow through the load device. During this no flow condition, the bridge circuit is said to be balanced. Quite often when the bridge circuit is used in an electronic test instrument, the load device is a very sensitive meter movement such as a galvanometer. Figure 2-28 shows a galvanometer, which indicates direction and amount of current flow, connected into a bridge circuit.

To determine the potential difference between points A and B, we could connect a voltmeter between these points. But instead let's find the answer by using Ohm's law. In a parallel circuit the applied voltage (Ea) is the same in all

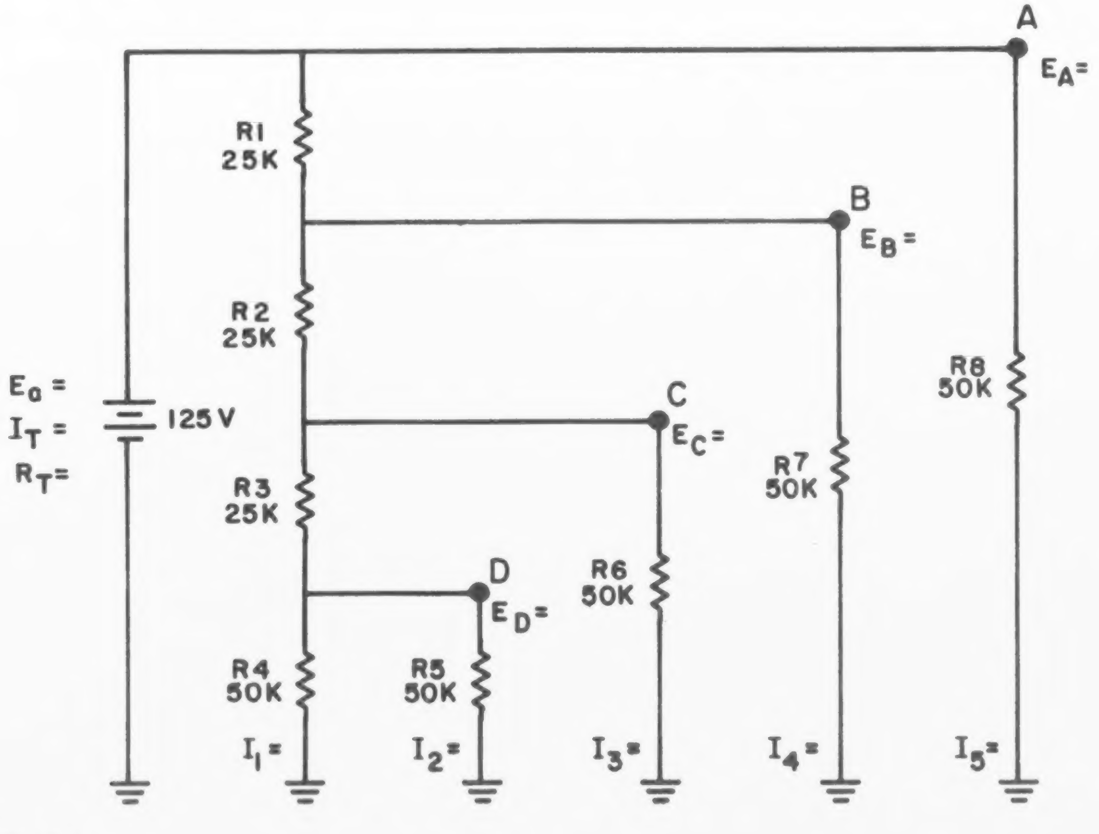

Figure 2-26. Voltage divider.

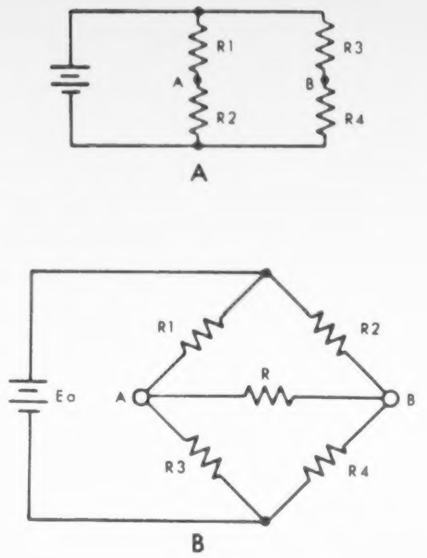

Figure 2–27. Bridge circuit.

branches. Add the resistance in each branch: branch A = 6 ohms; branch B = 9 ohms.

Now find the current through branch A and branch B by using the following Ohm's law formula:

$$I = \frac{E}{R}$$

You will find 3 amps flows through branch A and 2 amps through branch B. You are now ready to compute the potential at points A and B. Notice that a ground reference point has been added to the circuit. With ground at this point, the potential at points A and B is positive with respect to ground. So let's compute the voltage at these two points:

Branch A at point A

$$\begin{aligned} E &= I_A \times R_2 \\ &= 3_a \times 4\Omega \\ &= 12 \text{ volts} \end{aligned}$$

Branch B at point B

$$\begin{aligned} E &= I_B \times R_4 \\ &= 2_a \times 6\Omega \\ &= 12 \text{ volts} \end{aligned}$$

To find the potential difference between points A and B, you subtract the smaller voltage from the larger. In our case, this is zero volts. With 0 volts existing between the two points, no current will flow through the galvanometer. This is the condition of a balanced bridge.

Let's examine figure 2-28 a little closer. Note the relation of the value of R_1 (2Ω) to the value of R_2 (4Ω). The ohmic value of R_2 is twice that of R_1. You will also see a similar relationship between R_3 (3Ω) and R_4 (6Ω). This ratio relationship can be expressed in mathematical form:

$$\frac{R_1}{R_2} = \frac{R_3}{R_4} \text{ or } \frac{2\Omega}{4\Omega} = \frac{3\Omega}{6\Omega}$$

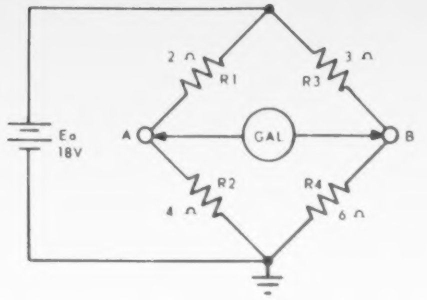

Figure 2–28. Bridge circuit (balanced).

This ratio is stated: R_1 is to R_2 as R_3 is to R_4. Cross multiplying numerators and denominators will yield the result, 12 ohms equals 12 ohms. The bridge is balanced.

You will also find in figure 2-28 that a ratio relationship also exists with R_1 to R_3 and R_2 to R_4.

$$\frac{R_1}{R_3} = \frac{R_2}{R_4} \text{ or } \frac{2\Omega}{3\Omega} = \frac{4\Omega}{6\Omega}$$

These ratio relationships between any two resistors in the vertical or horizontal plane exist in any bridge circuit. If the ratios are equal the circuit is balanced.

Unbalanced bridge circuits. We have been working with a balanced bridge circuit. The bridge circuit shown in figure 2-29 is unbalanced. Perhaps with your understanding of balanced bridge circuits you can already see, by looking at the value of the resistors, the bridge is in an unbalanced condition. A more positive way to determine whether the bridge is balanced or unbalanced is to use the ratio formula:

$$\frac{R_1}{R_2} = \frac{R_3}{R_4} \text{ or } \frac{7\Omega}{14\Omega} = \frac{3}{4}$$

By cross multiplication, 28 does not equal 42; therefore, the bridge is unbalanced. With the bridge unbalanced, a potential difference exists between points A and B. We can determine this potential difference by Ohm's law. Your calculation should show that 1 amp flows through branch A and 3 amps flow through branch B. Using the current flows and the resistance of R_2 and R_4, you can determine the voltage at points A and B. Your calculation should show that the voltage at point A is 14 volts and at point B is 12 volts. The potential difference between points A and B is 2 volts. Since point A is more positive than point B, current will flow from point B toward point A through the galvanometer. To balance the bridge circuit shown in figure 2-29 the size of R_1, R_2, R_3, or R_4 must change. Let's assume that we want to change R_4. We can use the ratio:

$$\frac{R_1}{R_2} = \frac{R_3}{R_4} \text{ or } \frac{7\Omega}{14\Omega} = \frac{3\Omega}{R_4}$$

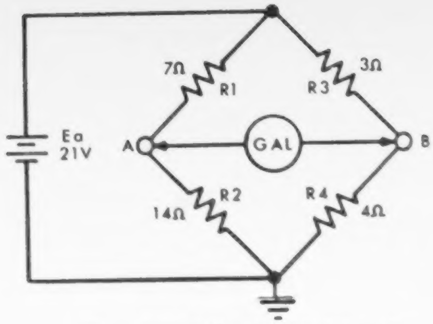

Figure 2–29. Bridge circuit (unbalanced).

Solve for the unknown (R_4) by cross multiplying.

$$7\Omega \times R_4 = 14\Omega \times 3\Omega$$

$$7R_4 = 42\Omega$$

$$R_4 = 6\Omega$$

We could replace R_4 with a 6-ohm resistor and have a balanced bridge. No potential difference would exist between point A and B, and the galvanometer would read zero.

Exercises (420):

1. Refer to figure 2-28 in your text. Identify the conditions that would exist if the bridge was balanced.

2. In an unbalanced bridge circuit, if the applied voltage is increased, what will happen to the current through the galvanometer?

3. Refer to figure 2-29 in your text. What value resistor must be substituted for R_3 to balance the circuit?

CHAPTER 3

Generators and Motors

AS AN ELECTRONICS specialist, you will be working on many systems that use generators and motors. There are many variations in application and in design of these devices; therefore, a thorough knowledge of their basic internal operation will make troubleshooting a system much easier. In this chapter we discuss another type of current called alternating current (AC) and how AC, as well as DC, is developed in generators. We also discuss how AC and DC are employed to drive motors.

3-1. Alternating Current

We previously described how current flows in a DC circuit. Now we are ready to consider a different type of current flow—alternating current. Alternating current is the term applied to a current that periodically reverses its direction. In this section, we discuss the calculation of waveforms and some of the frequency terms used in electronics.

421. Calculate the peak, effective, and average voltage from selected waveforms.

Waveforms. A plot of voltage or current versus time is called a waveform. If we plot a direct current versus time, we end up with a straight line. However, when we plot an alternating current, a current that periodically changes polarity, we can arrive at a variety of shapes. Depending on the method of generation, some of the more common waveshapes are the square, rectangular, sawtooth, and pulse. These waveshapes are used for triggering, timing, and computing circuits. The most commonly used waveform used in training devices, however, is the sinusoid or sine wave shown in figure 3-1. Notice that the sine wave increases to a maximum amplitude in one direction and then decreases to zero. It then increases to a maximum amplitude in the opposite direction and again decreases to zero. Now let's discuss in more detail the sine wave shown.

The sine wave results from a plot of the instantaneous current output of a generator due to the rotation of its armature. The length of the horizontal line in figure 3-1 represents the time of one rotation of such an armature. We have noted specific points of rotation of this line in both degrees and radians (a term that also represents the amount of angular rotation). What is a radian? You might recall from your earlier schooling that the circumference of a circle, distance around, is equal to 2π times its radius. We can describe a circle or any portion of its arc in terms of its radius. A full circle is therefore 2π radians or 360°, a half circle is π radians or 180°, a quarter circle is π/2 radians or 90°, etc. The time of one rotation or one generation of the sine wave represents its period.

Peak voltage. Notice that the horizontal line in figure 1 divides the sine wave into two equal parts—one above the line and the other below it. The portion above the line represents the positive alternation, and the portion below the line represents the negative alternation. Notice that the wave reaches its maximum swing from zero at 90 ° and 270°. Each of these points is called the peak of the sine wave. When we speak of the peak amplitude of a sine wave, we mean the maximum swing, or the height of one of the alternations at its peak. These terms apply to either current or voltage and are important to remember because you will be using them throughout your training devices career. As an example, suppose you have a sine wave with an amplitude of four units; that is, the peak of the sine wave is four graphic units (on the scope screen) from the zero reference line. Also suppose that each unit represents 10 volts. You can now find the amplitude of the voltage that the sine wave represents by multiplying the number of units by the value of voltage each represents. Thus, the peak amplitude is 40 volts (4 × 10 = 40). Another value of importance is the peak-to-peak value. This term, as shown in figure 3-1, represents the difference in value between the positive and negative peaks of a sine wave. Of course, this is equal to twice the peak value. Why is this term so important? Suppose that you wanted to find the amplitude (voltage) of a sine wave as you did previously. However, this time there was no zero reference. By dividing the peak-to-peak value by two, you get an accurate peak amplitude. Assume that each graphic unit on the scope represents 10 volts and there are 8 units between the peak-to-peak of the sine wave. The peak-to-peak value is then 80 volts and the peak value is 40 volts.

Effective voltage. A more useful value when dealing with AC is the effective value. The effective value of a sine wave of AC is the amount that produces the same heating effect as an equal amount of DC. Since the heating effect of a quantity of current is proportional to the square of the current, we can calculate the effective value by squaring the instantaneous values of all points on the sine wave, taking the average of these values, and extracting the square root. The effective value is, thus, the root of the mean (average) square of these values. This value is known as the "root-mean-square," or RMS value. When we speak of a voltage as having a value of 110 volts, we mean that it has an effective or RMS value of 110 volts. Unless otherwise stated, the AC voltage or current is expressed as the effective value.

We can derive a mathematical expression for effective or RMS value for one alternation of a sine wave by restating our definition as follows:

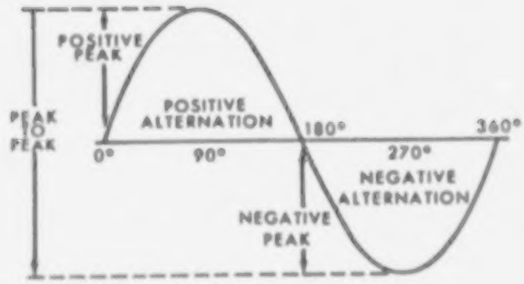

Figure 3-1. AC sine wave.

$$\text{RMS} = \frac{\sqrt{\text{area under the } I^2 \text{ curve (one loop)}}}{\text{length of one alternation}}$$

The area under the I^2 curve is analogous to that of a triangle or equal to one-half the base times the height or 1/2 (π rad.) (I^2 peak). Dividing this area by the length of one alternation (π rad.) will give us the mean or average value. Our formula is now:

$$\text{RMS} = \frac{\sqrt{\pi/2 \ (I^2 \text{ peak})}}{\pi}$$

solving

$$\text{RMS} = \frac{\sqrt{I^2 \text{ peak}}}{2}$$

Now suppose that we have a sine wave that represents a current with a peak value of one unit. Substituting this value in our formula:

$$I_{RMS} = \sqrt{\frac{(1)^2}{2}}$$

$$I_{RMS} = \sqrt{\frac{1}{2}}$$

$$I_{RMS} = \sqrt{\frac{1}{2}} = \frac{1}{1.414}$$

$$I_{RMS} = .707$$

The effective value of one unit of AC is therefore equal to Similarly, a sine wave of voltage whose peak value is 1 volt will have the same heating value as .707 volts of DC. To find the effective value of AC, therefore, multiply .707 times the maximum or peak value. The reciprocal of .707 is 1.414. Therefore, if you know the effective value you can obtain the peak value by multiplying the effective value by 1.414.

Average voltage. Another value in a sine wave that is important to know is the average value. This is the average of the instantaneous values of all points in a single alternation. (The average of a complete sine wave is zero.) The average of a sine function can be defined as the area under one alternation divided by the base of the alternation. The base of one alternation as in figure 3-1 is π radians. Unlike our computation of area under the I^2 curve we previously discussed, the area under a curved surface such as a sine wave is very complex. To save us a lot of math, accept the fact that the area of one alternation is equivalent to two times its peak value (voltage or current). The average value may then be defined by the following expression:

$$\text{Average value} = \frac{2 \text{ (peak value)}}{\text{(length of base)}}$$

or

$$\text{Average value} = \frac{2 \text{ (peak value)}}{\pi}$$

If the sine wave represented a voltage of 1 volt, we could say:

$$E_{AVE} = \frac{2(1)}{\pi}$$

Dividing the numerator and denominator by 2 yields:

$$E_{AVE} = \frac{1}{pi/2}$$

or

$$E_{AVE} = 1\frac{2}{\pi}$$

$$E_{AVE} = .637$$

The average height of a single alternation (positive or negative) is .636 times the peak value. The relationships between the average, effective, and peak values can be determined mathematically and are shown in the following formulas:

Average value = .636 peak value = .9 effective value
Effective value = .707 peak value = 1.11 average value
Peak value = 1.414 effective value = 1.57 average value

Exercises (421):

1. Calculate the peak, effective, and average voltage from a 200 peak-to-peak voltage.

2. Calculate the peak and average voltage from a 110 effective voltage.

422. Define frequency terms used in electronics.

Frequency Terms. As we stated before, alternating current is periodically reversing direction. We call two consecutive alternations, one positive and one negative, a full cycle. We often refer to the positive and negative alternations as half-cycles. The number of cycles that occur in a given time is called the frequency. The universally used unit of frequency is the hertz. Instead of saying, "60 cycles per second," you say, "60 hertz."

However, in electronics 60 hertz is a relatively low frequency. We often talk of frequencies in the thousands and millions. When we speak of frequencies in the thousands, we use the term "kilohertz." When we speak of frequencies in the millions, we use the term "megahertz." We have two other terms you will be using, "millihertz" and "microhertz." If one cycle is one thousandth of a second, the frequency is one millihertz. If one cycle is one millionth of a second, the frequency is one microhertz. These values are used in many computer circuits.

We have said that current or voltage may occur as sine waves. Since voltage is used to produce current, let us compare the sine waves in a different way than we have before. Figure 3-2 shows three sine waves. The top wave represents voltage. The two other waves represent the current by the voltage of the top wave.

Notice that the voltage sine wave A and the current sine wave B move together. Since the two sine waves go through all phases of the cycle together, they are in phase. We do not limit the use of the term "in phase" to just the voltage and the current produced by the voltage. Two alternating voltages or two alternating currents that rise and fall together are "in phase."

Current is in phase with the voltage only in circuits that are purely resistive. You will find that there are electrical components which affect the voltage and current phase relationships in AC circuits. Whenever one of these components is included in a circuit, an out-of-phase relationship exists between current and voltage.

An out-of-phase relationship exists any time the waves do not move simultaneously. This out-of-phase relationship can be seen by comparing sine wave A and sine wave C in figure 3-2. The current sine wave is maximum negative when the voltage sine wave is zero (at the start of its positive half-cycle). When describing this relationship, we say that the current lags the voltage by 90°. If the action of the current sine wave occurs before that of the voltage, we say that the current leads the voltage.

Exercises (422):

1. Define the following terms:

   a. Kilohertz.

   b. Megahertz.

   c. Millihertz.

   d. Microhertz.

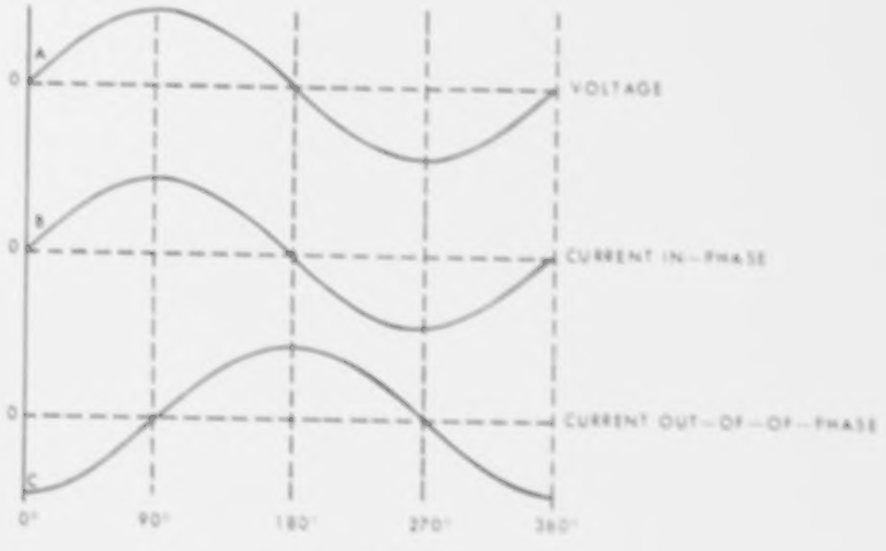

Figure 3-2. Phase relationship.

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2. What is meant by an out-of-phase relationship?

3-2. Alternating and Direct Current Generators

First, we will discuss the three requirements for induction; second, how alternating current is developed by moving a conductor through a magnetic field; third, the factors that determine the magnitude of the current flow and the components of an AC generator; fourth, the components of DC generators and how DC is generated; and finally, three different types of DC generators.

423. List the three requirements for induction.

Requirements for Induction. Three requirements are necessary for induction. There must be a conductor (a coil of wire), a magnetic field (a permanent magnet), and motion between the magnetic field and the conductor in such a way that the conductor cuts across the magnetic lines of force or the lines of force cut across the conductor. In our discussion, this relative motion will be produced by moving the magnet. The relative motion could also be produced by holding the magnet stationary and moving the coil.

Exercises (423):

1. What are the three requirements for induction?

424. State how current is affected by moving a conductor through a magnetic field.

Direction of Current in a Conductor. Figure 3-3,A, shows a conductor moving downward through a stationary magnetic field with lines of force that go from left to right. Notice that we now have the three requirements necessary for induction. As the conductor moves down through the field, the field tends to encircle the conductor in a counterclockwise direction. This induces a voltage into the conductor. The resultant voltage causes current to flow in the conductor. Figure 3-3,A, shows that the current in the conductor is flowing away from us (into the page) and is represented by placing an X or a + in the center of the conductor.

Now observe what happens when we move the conductor through the field in the opposite direction, as shown in figure 3-3,C. You can see that lines of force encircle the conductor in a clockwise direction. Therefore, the current is flowing toward you (out of the page); this is shown by the dot in the center of the conductor. This change in direction of relative motion produces a change in the direction of current flow in the conductor. Figure 3-3,B, shows the conductor moving parallel to the lines of force. Notice that the lines of force do not encircle the conductor as they did when the conductor was moved up or down; thus, no voltage is induced in the conductor.

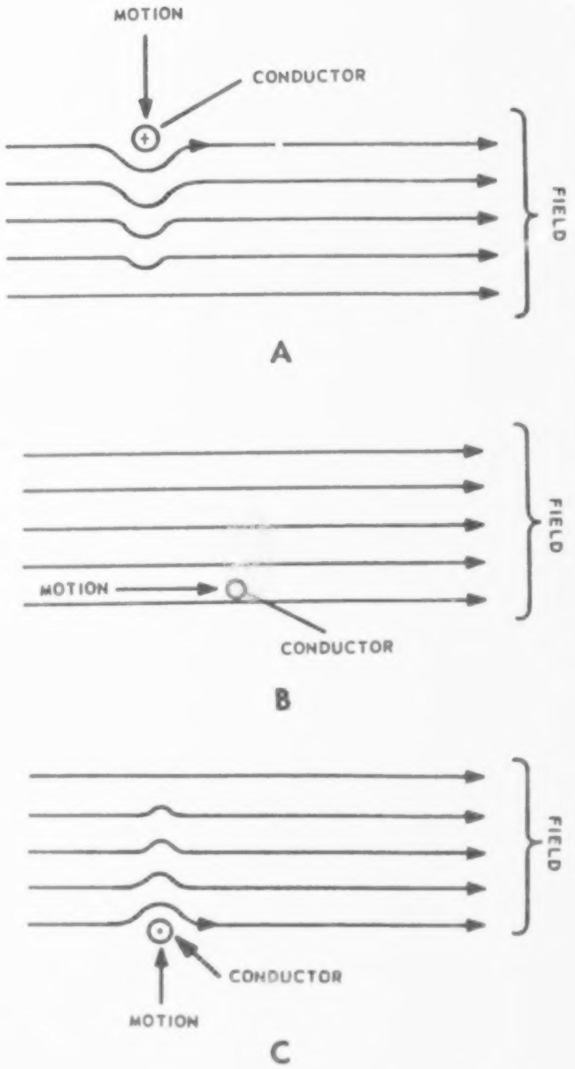

Figure 3-3. conductor moving through a magnetic field.

Notice what happens when we rotate a loop of wire in a magnetic field. In figure 3-4 we see a cross section of the two ends of the loop: one at A and the other at B. At the instant the loop is in the position A–B (shown in figure 3-4,A), the conductor is moving parallel to the lines of force and no current is induced in the loop.

As the loop is rotated from A–B to A2–B2, it cuts across the lines of force until it cuts a maximum number at 90° (position A2–B2). If you look at the conductor at A2 you find that the current is going into the conductor (away from you) as indicated by the "+" symbol. At the same time, we find that the current is coming out of the conductor (toward you) in B2 as indicated by the dot. In other words, the current flow is from A2 to B2.

Now assume that the loop is rotated further to position A3–B3 as shown in figure 3-4,B. The amount of current induced decreases until it reaches zero at position A3–B3.

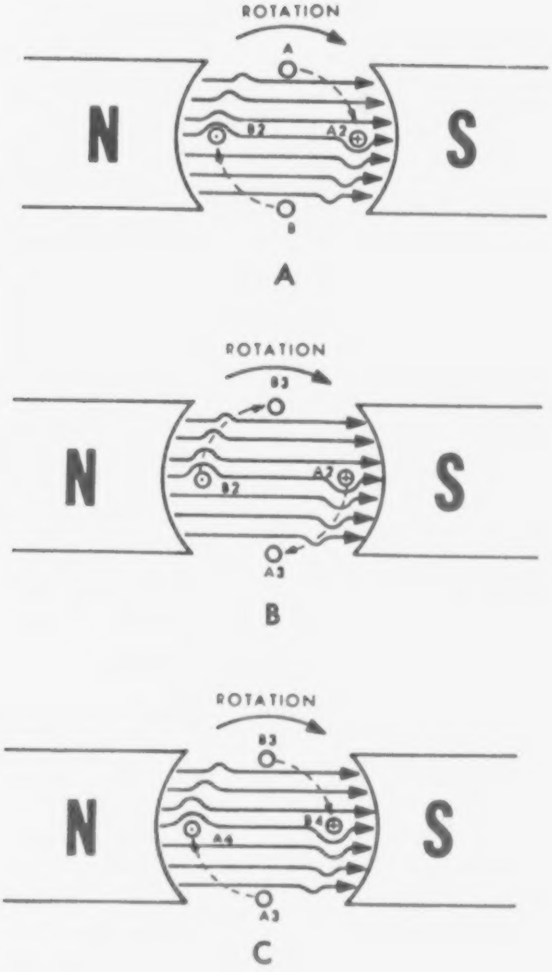

Figure 3-4. Rotating a loop of wire in a magnetic field.

At any position between A2 and A3, the current is going into the conductor. As end B moves from position B2 to B3, the current is coming out of the conductor. You can now see that as the loop is rotated from position A–B to A3–B3, the current induced in the loop varies from zero to maximum and back to zero, and the current flow is from A to B. (Keep in mind that current flow exists only when there is a complete loop, or closed circuit.)

As the loop continues to rotate from A3–B3 to A4–B4, as shown in 3-4,C, we can see that the loop again cuts lines of force. This again causes a voltage to be induced into the loop. However, the A end of the loop is now cutting the lines of force in the opposite direction. Now, the dot symbol shows that the current is coming out an A. We find that the B end is also cutting the field in the opposite direction. The "+" symbol shows that the current is now going in at B. In other words, the current flow is from B to A in the loop. When the loop reaches position A4–B4, the current flow is at maximum; but current now flows in the opposite direction. It flows from B to A, rather than from A to B as it did at the A2–B2 position.

Now look at figure 3-5 and plot the current in loop A–B as the loop is rotated 360°. At the starting position 0° (A–B in fig. 3-4,A), the current flow in the loop is 0. As the loop is rotated 90° to position A2–B2, the current rises to a maximum. The direction of current flow (A to B) is shown by plotting it above the zero current line.

As the loop continues to rotate from 90° to 180°, the current flow remains A to B (position A2–B2 to A3–B3 in fig. 3-4,B), but the current drops back to zero. Rotation from 180° to 270° (A3–B3 to A4–B4 in fig. 3-4,C) causes the current to rise from zero to a maximum, but the direction of flow is now B to A. This is shown in figure 3-5 by plotting it below the zero current line. Finally, as the loop rotates from 270° to 360°, the current falls from maximum to zero, although the current flow remains from B to A.

Notice how plotting the current graph for one revolution of the loop fits our definition of AC. The amplitude is continuously changing and the polarity is periodically reversing.

Exercises (424):

1. If a conductor is moved perpendicular to the line or force, back and forth through a magnetic field, how will current flow in the conductor?

2. What magnitude is the induced voltage in a conductor when the conductor is moving at 90° to the magnetic lines of force?

425. State how current flow in a conductor will be affected if the three basic requirements for induction are varied.

Varying the Factors that Determine Magnitude of Current Flow in a Conductor. You learned the three requirements necessary for induction: a conductor, a magnetic field, and relative motion between the conductor and the field. Now let's see what effect changing one of these three requirements has on induced voltage. Basically, the magnitude of the induced voltage depends on the number of lines of magnetic force that the conductor cuts in a given period of time. This may be varied in any one of three ways.

First, look at figure 3-6,A. Notice that the magnetic field has considerably fewer lines of force than that of figure 3-6,B. Thus, at the same speed of rotation, the conductor in figure 3-6,B, is cutting more lines of force than the conductor in figure 3-6,A. The result is that the conductor in figure 3-6,B, has a higher induced voltage and thus a higher current flow. A stronger magnetic field induces a higher voltage in the conductor.

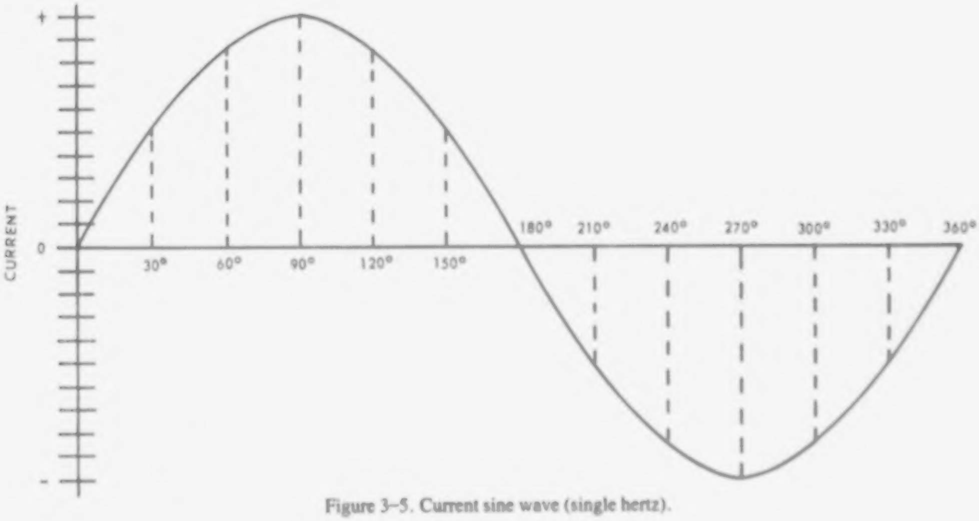

Figure 3–5. Current sine wave (single hertz).

What happens when we vary the relative motion between the conductor and the magnetic field? If it takes the conductor one second to move from one position to another through the lines of force, the conductor cuts six lines of force per second. Now, suppose we slow the conductor so that it takes 2 seconds to move from one position to another through the lines of force. The conductor is now cutting only three lines of force per second, and its voltage is reduced.

The third change that varies the magnitude of the induced voltage is the number of conductors. If we use a single-loop conductor as we did in all of our previous discussions, the generator will have a certain output. Now if we use a conductor that forms two or more loops, each loop will have approximately the same current in it as the single loop. These currents, however, are in series, so the total output will increase as each loop is added.

Again, the three things that determine the magnitude of the current are: the strength of the magnetic field, the speed of rotation, and the number of conductors. Increasing any one of these (without decreasing the other two) increases the magnitude of the current. On the other hand, decreasing any one of the three, while the other two remain constant, decreases the magnitude of the current.

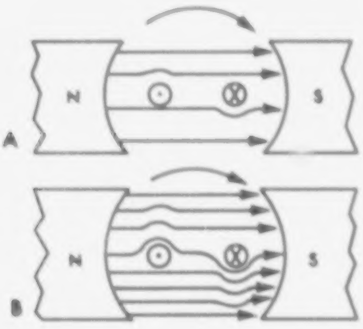

Figure 3–6. Rotating conductor.

Exercises (425):

1. Name the three things that vary the magnitude of induced current in a magnetic field.

2. What happens to the AC output if we increase the speed of rotation of the conductor? Why?

426. Name the components of an AC generator and state their functions.

Components of a Basic AC Generator. You should now have a fair understanding of how AC is generated. The pole pieces are the two ends of a magnet, and the field coil provides the magnetic lines of force at the pole pieces. The armature is the part that rotates, and it includes sliprings and windings around a core. There is the source of mechanical power that causes the armature to rotate. The sliprings are two metal rings mounted on the armature shaft, one ring for each end of the rotating conductor. The brushes are stationary contacts that ride on the sliprings to pick up the induced current and voltage.

The pole pieces provide a path for the magnetic lines of force. They have curved faces to spread the flux uniformly across the space for the armature. In some cases, these pole pieces are permanent magnets; in other cases, electromagnets are used to provide the magnetic field. The generator is constructed so that the pole pieces and generator frame form a low-reluctance path for the magnetic field.

The rotating conductor is the winding on the armature core. The armature core provides a means of mounting and rotating the conductor, as well as providing a low-reluctance path between the pole pieces. As the conductor rotates in the magnetic field, it cuts magnetic lines of force, inducing a voltage in the rotating conductor.

The sliprings rotate with the armature, while the brushes remain stationary and slide over the surface of the sliprings. This provides a means of transferring the induced current from the rotating conductor to.a stationary external circuit.

The external circuit and load provide a path in which the induced current flows so that it can be used to perform work. The load may consist of any devices that conduct current, such as lamps, motors, and transformers.

Exercises (426):

1. Name the components of a basic AC generator.

2. State the function of the following AC generator components.

   a. Pole pieces.

   b. Rotating conductor.

   c. Sliprings.

   d. External circuit.

427. Compare the DC generator with the AC generator and list its (DC generator) basic components.

Components of a Basic DC Generator. The components of the basic DC generator are very similar to those of the basic AC generator. As a matter of fact, the only difference is the use of commutator segments rather than sliprings. The commutator segments provide a means of switching the connections to the external circuit each time the voltage induced in the armature changes polarity.

The pole pieces provide a path for the magnetic field. This magnetic field comes from either a permanent magnet or an electromagnet (formed by a field coil wound on the pole pieces). The armature provides a means of mounting and rotating the conductor within the magnetic field. The brushes provide a means of connecting the rotating electrical circuit of the armature with the stationary external circuits. Both brushes ride on the same commutator, but are positioned so that they connect to opposite sides of the commutator.

Exercises (427):

1. What is the difference between a basic DC generator and an AC generator?

2. List the components of a basic DC generator.

428. State how a commutator affects voltage.

How DC is Generated. Notice the position of the loop in figure 3-7. The conductor is moving parallel to the magnetic field. At this position there is no voltage induced in the loop. Notice also that the brushes are across the opening between the commutator segments. As the loop rotates through 90° from this position, a maximum voltage is induced in the conductor, causing current flow in the loop from A to B, as shown in figure 3-8. This causes current to flow out the left-hand brush, through the load in the direction indicated by the arrow, and back to the right-hand brush. When the loop reaches the 180° position, the induced voltage again becomes zero. Also, at this time the commutator has turned 180° and the brushes are across the opening.

As the loop rotates to the 270° position, a maximum voltage is induced in the loop, causing a current flow within the loop from B to A. Because the left-hand brush is now riding on commutator segment A, current will flow out the left-hand brush, through the load in the direction indicated by the arrow, and back to the right-hand brush. Finally, as the loop continues to the 360° position, the induced voltage again returns to zero.

From this discussion you can see that although the current induced in the loop reverses for every 180° rotation of the loop, the commutator switches the external circuit so that the current through the external circuit remains in the same direction. When the loop is at 0° (fig. 3-7), the voltage across the load is zero. When the loop is at 90° (fig. 3-8), the voltage across the load is maximum. At 180°, the voltage again becomes zero; at 270°, the voltage is again maximum, and it returns to zero at 360°.

The voltage across the load does not reverse polarity. It varies from zero to maximum. This is a pulsating voltage. We can define a pulsating DC voltage as a DC output that periodically drops to zero. The DC output of the generator can be made smoother by adding a second loop to the generator. This second loop will be at 90° to the original loop. The commutator will now have four segments. With an armature of this type, the induced voltage of one loop is at maximum while that in the other loop is at zero. If the brushes are positioned properly, they furnish the maximum voltage to the external circuit during the time that each loop is at maximum. In order to produce a DC with smaller variations, we can simply add more loops.

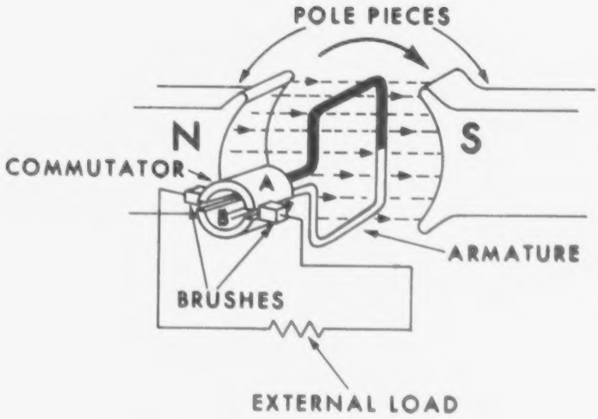

Figure 3–7. Components of a basic DC generator.

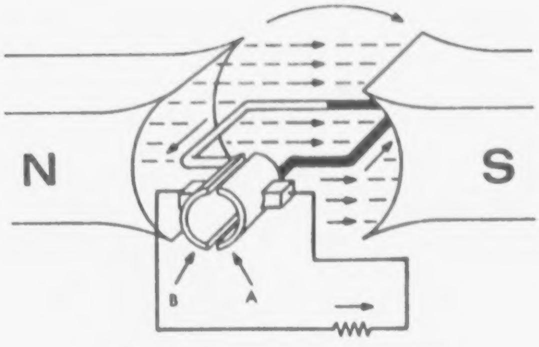

Figure 3–8. Current flow in a rotating loop.

Exercises (428):

1. In a basic DC generator, what will the voltage output be at 180° of rotation of the conductor?
2. What is the output of a DC generator when a second loop is added?

429. Specify how three types of DC generators operate.

Types of DC Generators. You are now going to study three types of DC generators: series, shunt, and compound. These classifications are based on the relationship between the field and the armature wings.

Series generators. A series generator exists when the field coil and the armature winding (ARM) are in series, as shown in figure 3-9,A. Figure 3-9,B, shows the output voltages versus load current of a series generator. Observe that without a load no current can flow through the generator. The output voltage with zero load current results from residual magnetism in the pole pieces. As load current increases, field strength increases; the rotating armature coil cuts more magnetic lines and output voltage increases. Notice that we have shown a rheostat in parallel with the field coil. This rheostat is used to regulate the field current which, in turn, controls the generator output.

Shunt generators. Figure 3-10 shows a shunt generator. In this second type of generator, the field coil is in parallel with the armature and load. Field current can flow when no load is connected. Figure 3-10 shows maximum output voltage with zero load current. A rheostat is placed in series with the field to control this generator putput. Notice that, in the shunt generator with a load connected (fig. 3-10,A), the current induced in the armature flows in two paths—part flows through the field and part flows through the load. As load current increases, output voltage decreases. Compare this with the series generator, where all of the current induced in the armature flows through the load. Notice that the charts of figures 3-9,B, and 3-10,B, show the rated voltage and rated current values are the same, but above and below these values, characteristics vary greatly.

Compound generators. Another type of DC generator combines series and shunt characteristics and is called the compound generator (fig. 3-11). The compound generator has two field windings; one is a series winding and the other

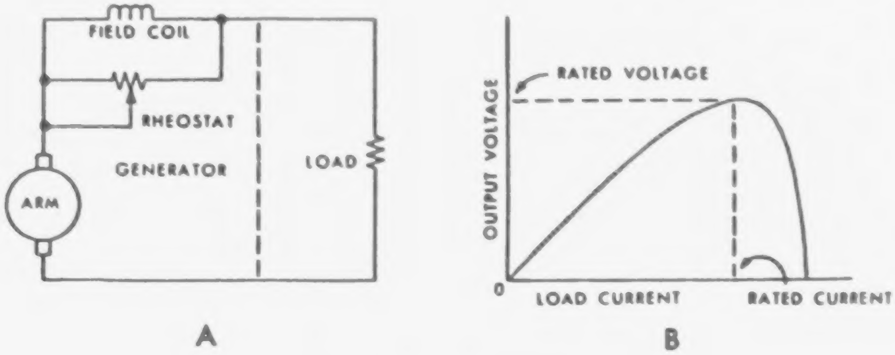

Figure 3–9. Series DC generator.

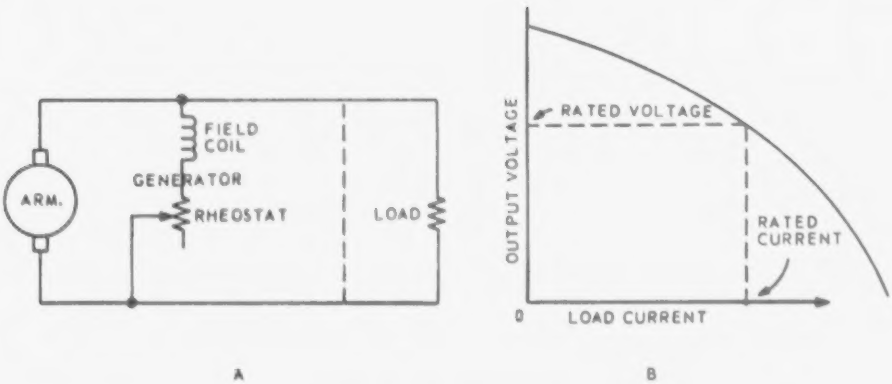

Figure 3–10. Shunt DC generator.

a shunt winding. Thus, a desired voltage can be built up without a load (shunt characteristic), and when a load is connected, field strength is increased (series characteristic). Adding the series winding to the shunt generator offsets the voltage decrease that results when a shunt field only is used. The compound generator has better regulation, that is, it has a more uniform output voltage with changing load. Compare figure 3-11,B, to figures 3-9,B, and 3-10,B.

Exercises (429):

1. What is the purpose of having a rheostat in parallel with the field coil of a series DC generator?

2. Explain the current path in a DC shunt generator with a load connected.

3. Which type of DC generator would we use if we wanted the best voltage regulation? Why?

3-3. Alternating and Direct Current Motors

In this section we discuss alternating current motors. We start by discussing how a 3-phase power supply provides a rotating field with stationary windings and how this rotating field is used to operate induction and synchronous motors. We describe the use of single-phase power to create a rotating field for low-power type motors, the structural differences in AC and DC motors, and types of AC starting devices.

430. State how a basic AC motor operates and tell when there is maximum current flow.

Rotating Magnetic Field. The upper half of figure 3-12 is a simplified schematic of a 3-phase stator (stationary field windings) to which a 3-phase voltage is applied. The magnetic field generated by one coil depends upon the current through it. If the current is zero, the magnetic field is zero. When the current is maximum, the magnetic field is maximum. Since the currents applied are 120° out of phase the magnetic fields generated are also 120° out of phase. The three magnetic fields combine to produce one field that, in turn, acts upon the motor rotor. The angular position of this magnetic field is constantly shifting at a constant rate. The magnetic field shifts through 360° for each cycle of the applied voltage.

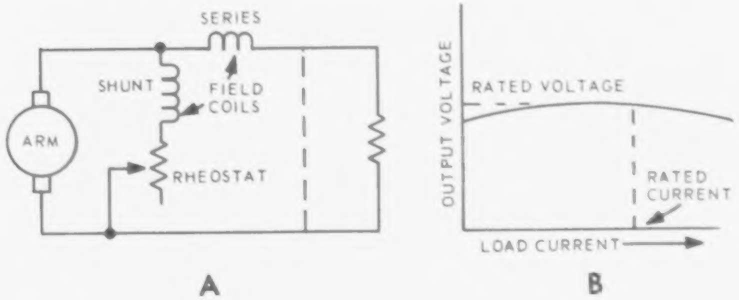

Figure 3–11. Compound DC generator.

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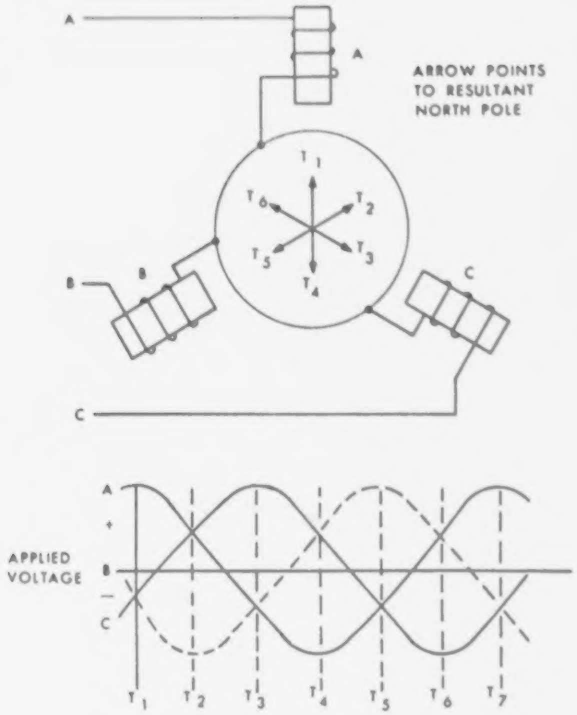


Figure 3-12. Simplified schematic of a 3-phase stator with a 3-phase voltage applied.

Referring to figure 3-12, the arrows in the center of the three coils point to the north pole, which is established by the three windings and the wave shapes in the lower half of figure 3-12. Referring to both parts of figure 3-12, at time T_1, you can see that voltage at point A is maximum positive while B and C are at equal negative potentials. Equal amounts of current flow through coils B and C and combine to flow through coil A. You can see that A has the greatest magnetic strength, indicated by arrow T_1.

At time T_2, points A and C have equal positive voltage, with maximum negative potential at B. Thus, current flows in B and out A and C. Coil B has the greatest strength and arrow T_2 points in a direction opposite the south pole, toward a point midway between the north poles of A and C.

At time T_3, point C is maximum positve, with A and B at equal negative potentials. Current flows in A and C and out C, making coil C have the greatest strength and a strong north pole for arrow T_3.

Follow this same approach for times T_4, T_5, and T_6. You will find that the arrow makes a complete revolution for each complete cycle of the applied 3-phase voltage.

Figure 3-12 shows coils B, and C at 120° positions. Each of these three coils can be split and placed on opposite sides of the circle to form 60° magnetic positions as shown in figure 3-13. This provides smoother transition for the rotating magnetic field. Assume that you pivot a magnet at the center of the coils and follow the current through one cycle of applied voltage. You will find that the stationary windings provide a rotating magnetic field, and the magnet follows this field as it rotates through 360°. This is a basic principle in the operation of AC motors.

Exercises (430):

1. State the basic principle of an AC motor.

2. Refer to figure 3-12 of your text. At time T_2, which coil has maximum current flow?

431. State synchronous motor operating principles.

Synchronous Motors. In a synchronous motor, the permanent magnet is replaced with an electromagnetic rotor, energized by DC. Sliprings and brushes are used to make connections for the steady current through the rotating electromagnet.

As the AC magnetic field in the stator rotates, the DC field rotates to keep aligned with it. The speed of the rotating field depends on the frequency of the applied AC. The synchronous motor cannot operate at any speed except that of the rotating field. This type motor is used where it is important to maintain constant speed.

Synchronous speed, or the speed of the rotating magnetic field, depends on the frequency and the number of pole pairs. By the pole pairs, we mean the number of coil groups acting together. A 3-phase input, for example, may be wound on six different stator coils but set as a single pair of poles. On the other hand, the six stator coils may be wound to act as 2- or 3-pole pairs. The number of poles divided by 2 equals the number of pole pairs.

If the number of pole pairs and the applied AC frequency are known, synchronous speed may be determined by the formula:

$$\text{rpm} = \frac{60 \times \text{applied frequency}}{\text{number of pole pairs}}$$

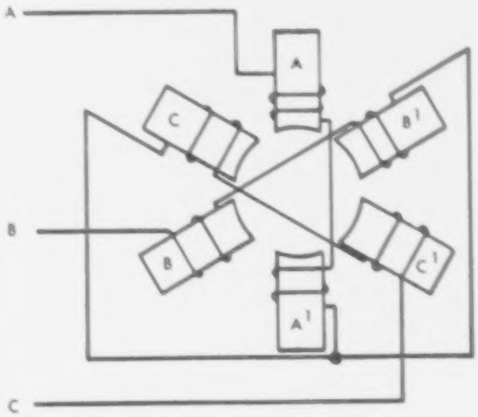


Figure 3-13. Coils split at 60° positions.

The synchronous speed of a 2-pole motor operating on 60 hertz is:

$$\frac{60 \times 60}{\frac{(2)}{(2)}} = 3600 \text{ revolutions per minute}$$

Exercises (431):

1. What determines a synchronous motor's speed?

2. What is the formula for the synchronous speed of a 2-pole motor?

432. State induction motor operating principles and characteristics.

Induction Motors. In the induction motor, there are no connections to the rotor; it is a self-contained unit. The induction motor derives its name from the fact that currents are induced in the rotor by the rotating magnetic field of the stator.

The rotor of the induction motor is a laminated cylinder with slots in its surface. The windings in these slots are one of two types. The more common, a squirrel cage winding, consists of heavy copper bars connected together at each end by a metal ring. The other type of winding contains shorted coils of wire placed in the rotor slots. This type of rotor is called a wound rotor.

Whether wound or squirrel cage, the basic principle of operation is the same. This motor operates on the transformer principle, with the stator acting as the primary winding and the rotor acting as the secondary winding. When an alternating current is applied to the primary of a transformer, a varying magnetic field is established, inducing a voltage into the secondary winding. The rotating magnetic field generated by the stator induces a voltage in the rotor. When voltage is induced, current flows and creates a magnetic field. Thus, we have a rotor magnetic field which interacts with the stator magnetic field.

As you learned previously, the magnetic field of any induced current opposes the changing field that induces it. In the case of an induction motor, the change is the motion of the resultant stator field, and the force is exerted on the rotor by induced current. It tries to cancel out the continuous motion of the stator field—that is, the rotor will move in the same direction, as close to the synchronous speed as its load and torque will allow.

It is impossible for the rotor of an induction motor to turn at the same speed as the rotating magnetic field, If the speeds were the same, no relative motion would exist between the two and no induced current would result in the rotor. Without the induced current, a turning force would not be exerted on the rotor. The rotor must rotate slower than the rotating magnetic field if relative motion is to exist between the two. The percentage difference between the rotational speed of the stator field and the rotor is called slip. The smaller the slip, the closer the rotor speed approaches the stator field speed.

The speed of the induction rotor depends upon the torque requirements of the load. The larger the load, the higher the torque needed to rotate the rotor. Torque can increase only if the rotor-induced current increases, and current can increase only if the magnetic field cuts through the rotor at a faster rate. To increase the relative speed between the field and rotor, slip must increase. Therefore, for heavier loads, the induction motor will turn slower than for lighter loads. Actually, only a slight change in speed is necessary to produce the current changes required for normal changes in load. This is because the rotor windings have a low resistance. As a result, induction motors are called constant-speed motors.

A single-phase induction motor uses only one stator winding for running. This winding generates a field that alternates along the axis of the single winding, rather than rotating. If the rotor is stationary, the expanding and collapsing stator field induces current in the rotor. These currents generate a rotor field exactly opposite in polarity to that of the stator. The opposition of the field exerts a turning force on the upper and lower parts of the rotor, trying to turn it 180° from its position. Since these forces are exerted through the center of the rotor, the turning force is equal in each direction. As a result, the rotor does not turn.

However, if the rotor is stated, it will continue to rotate in the direction in which it is started, since the turning force in that direction is aided by the momentum of the rotor.

Exercises (432):

1. From what electronic principle does an induction motor derive its name?

2. What makes up a squirrel cage rotor?

3. What causes the rotor to follow the rotating stator flux?

4. What is "slip" in an induction motor?

433. Explain the term "split phase" as it relates to starting induction motors, and identify different types of induction motors.

Methods for Starting Induction Motors. We have shown how the single-phase motor will continue turning once it has been started. However, we did not discuss the methods used for starting. Some electrical device must be incorporated into the stator circuit to generate a rotating field for starting. Once the motor is started, this device may be switched out of the stator circuit, and the rotor and stator tegether will generate their own rotating field to keep the motor turning.

Split-phase induction motor. The term "split phase" refers to what happens to the single-phase input voltage within the motor. The single-phase input is "split" by inserting a capacitor or resistor in series with one field coil winding.

Capacitor start. One type motor uses a combination of capacitance, inductance, and resistance to develop a rotating field for turning the rotor. This type of induction motor is called a capacitor-start type. The stator circuit consists of two legs. One leg has the main winding, and the other leg has the start winding. The windings are spaced at right angles to each other. Phase difference between the two windings is obtained by connecting a capacitor in series with the start winding. The closed start switch places the series-contained start winding and capacitor in parallel with such a value that current in the start winding leads the line voltage by approximately 45°. The run winding has enough inductance and resistance to cause current to lag the line voltage by approximately 45°. The two currents are 90° out of phase, as are the two magnetic fields they generate. The result is a 2-phase magnetic field that starts the rotor turning.

At 60 percent of full speed, the start switch opens and the motor runs as a single-phase induction motor. The capacitor needed for starting is quite large in order to allow a large current to flow. This develops a large starting torque. Since a 2-phase induction motor has better running characteristics than a single-phase motor, the start winding is often left in the circuit during run so the motor operates as a 2-phase induction motor. During run, current in the start winding must be reduced to prevent heat damage. This is accomplished by having two capacitors in parallel during start and removing one during run. Such a motor is called a capacitor-start, capacitor-run induction motor.

Resistor start. Another type of split-phase induction motor is the resistor-start motor. Like the capacitor-start motor, it has a start winding, but there is a resistor in series with the start winding. The phase shift between the currents in the two windings is obtained by making the impedance of the windings unequal. The main winding has a high inductance and low resistance. The current will therefore lag the voltage by some large angle. The start winding has a low inductance and a high resistance. Here the current will lag the voltage by some smaller angle. The currents will be out of phase, and the magnetic fields will be out of phase by the same amount. Although the ideal angular phase difference is 90° for maximum torque, this smaller phase difference will still generate a rotating field to start the motor. When the motor reaches the required speed, the start switch disconnects the starting winding from the line.

Shaded-pole induction motors. The shaded-pole induction motor is a single-phase motor that uses a unique method to start the rotor. The effect of a moving magnetic field is produced by a specially constructed stator. The shading coil is short-circuited. As the magnetic field in the pole piece builds up, a current is induced in the shading coil. This current builds a magnetic field around the field winding. The main field will therefore concentrate on the opposite side of the pole piece. The result is that the field inside the shading coil reaches maximum intensity later than the main field of the pole piece. As the main field of the pole piece begins to decrease, the shading coil field will aid the main field, and the concentration of flux moves to the area inclosed within the shading pole. The resulting field inside the shading coil reaches zero sometime after the main field.

This produces a small sweeping motion of the main field from one side of the pole piece to the other as the field pulsates. This motion is enough to start the motor rotating. This type motor is normally made only in very small sizes in the range of 1/50 hp.

Exercises (433):

1. To what does the term "split phase" refer in relation to induction motors?

2. Explain how the single phase is split for providing a starting force.

3. What type of induction motor has two parallel capacitors connected to its field during the start sequence, but has only one capacitor connected to the field winding after the start sequence is completed?

4. Which type of induction motor has a very small horsepower output?

434. State how magnetic force moves a conductor.

Force Exerted Between Magnetic Fields. All motors operate on the same fundamental principle: A force is exerted between stationary and movable magnetic fields. The amount and direction of this force, which results from interactions of the two magnetic fields, determines motor speed and direction of rotation. In order to determine the amount of force and its direction, the strength and polarity of both magnetic fields must be known.

You learned earlier that a current-carrying conductor has a magnetic field surrounding it. Polarity of the magnetic field depends upon the direction of the current. When a current-carrying conductor is placed between the poles of the magnet as shown in figure 3-14, interaction of the magnetic fields forces the conductor to move. In 3-14,A, notice the current is flowing away from you as indicated by the arrow. This causes magnetic lines of force to circle the conductor counterclockwise (CCW). This CCW force drives the conductor up and out of the field. Note that the magnet's lines of force below the conductor are in the same direction as the lines of force around the conductor. Recall that lines of force in the same direction repel each other. This repelling action causes instantaneous distortion of both fields, which forces the conductor upward. The conductor's lines of force above the conductor oppose the stationary magnetic lines. This opposition redirects the stationary magnet's lines to further strengthen the lower magnetic field, adding to the upward force on the moveable magnetic field. The direction of this force is perpendicular to the stationary magnet's field.

Figure 3-14,B, shows the direction of current flow reversed; the direction of force acting upon the conductor is also reversed. This condition forces the conductor to move downward.

Exercises (434):

1. Briefly explain the fundamental principle on which all motors operate.

2. Assume that a conductor is placed in a magnetic field perpendicular to the lines of force. How is the motion of the conductor affected when current flow in it is reversed?

435. State the characteristics of neutral plane, torque, current, and EMF as they affect the operation of a basic DC motor.

Basic Direct-Current Motors. A motor requires a turning force, which is called torque. In a motor, the current-carrying conductor is formed into a coil and placed on a shaft. The coil is free to rotate within the stationary magnetic field. The interactions of the magnetic fields develop the torque which causes the shaft to turn.

Figure 3-15 illustrates a basic DC motor that has one coil and two stationary brushes attached to a battery. The three components of this motor are the fixed magnet (stator), the coil winding (armature), and the commutator-brush assembly.

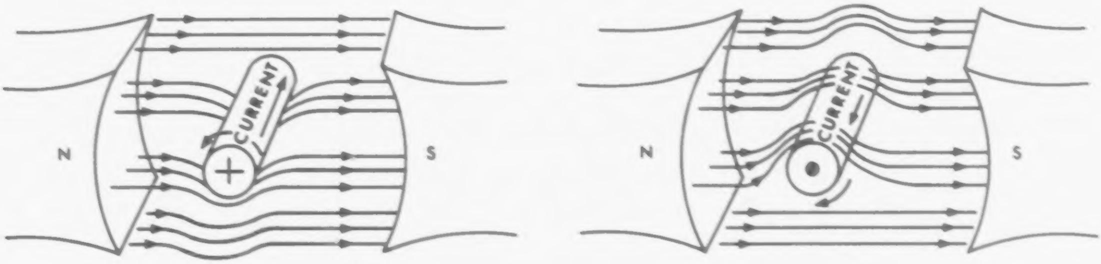
In figure 3-15,A, current through the dark portion of the coil sets up a CCW field, and current through the white side of the coil sets up a clockwise (CW) field. The interaction of these fields with the fixed field produces a CW torque, forcing the coil to move clockwise.

When the coil reaches the neutral plane (fig. 3-15,B), coil current drops to zero. Coil current rapidly builds back up to maximum, however, as soon as momentum moves the coil past the neutral plane and the brushes make contact with the opposite commutator segments. Note that in figure 3-15,C, the direction of the current flow through each coil side has been reversed and, as a result, torque remains CW.

When the coil is parallel to the fixed field's lines of force, as shown in figure 3-15,A, the torque is maximum. When the coil is rotated 90°, torque is minimum. Thus, the torque of the basic motor is zero in the neutral plane. This feature is undesirable in that it causes jerky coil movement and prevents the motor from starting if the coil is in the neutral plane.

Increasing the strength of the field magnet and placing additional coils within its field can increase torque. Stronger and less variable torque is developed in this type of motor than the torque developed by the single turn motor shown in figure 3-15. A motor having several armature windings is also self-starting, since at least one coil is always in a position to develop torque.

The resistance of armature coils is very small, usually less than 1 ohm. If we assume .5 ohm of resistance with 100 volts applied, we would expect armature current to be 200 amps. This large current could destroy the motor. Actually, the armature current is much less than 200 amps due to a



CONDUCTOR MOVES UP!

CONDUCTOR MOVES DOWN!

Figure 3–14. How a current-carrying conductor moves in a magnetic field.

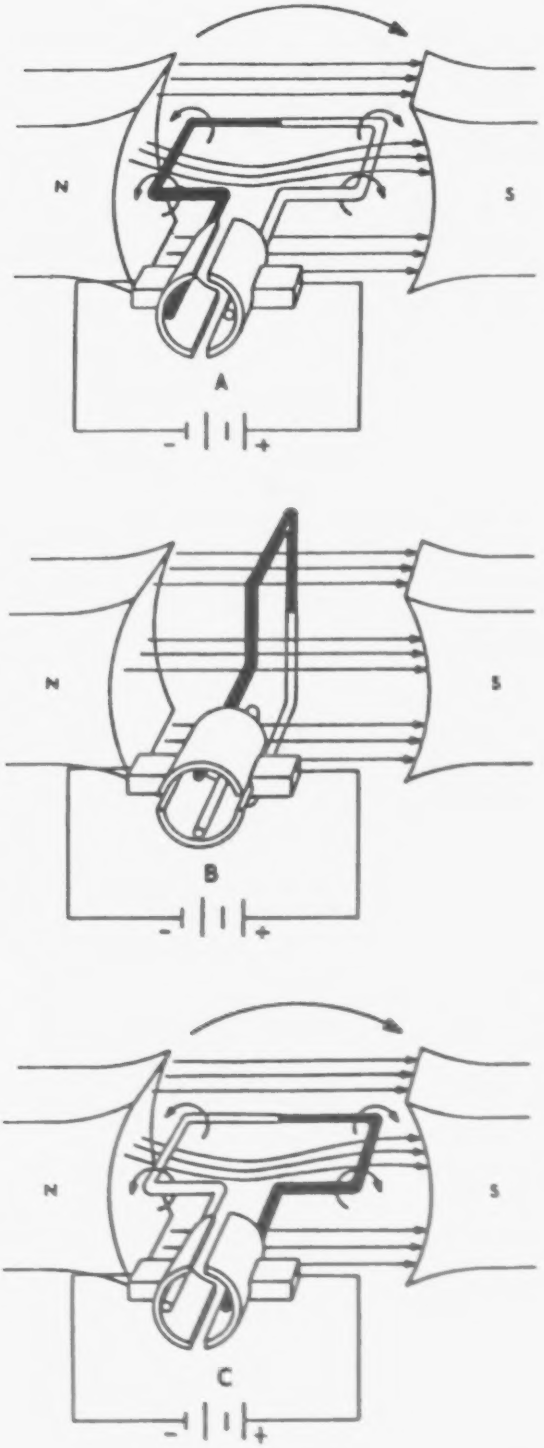


Figure 3–15. Basic DC motor attached to a battery.

voltage induced in the armature as it moves within the magnetic field.

This induced voltage can be compared to the EMF produced by a generator. A generator converts mechanical energy into electrical energy. Using a mechanical force to move a conductor through a magnetic field results in induced EMF in the conductor. The polarity of the induced EMF is determined by Lenz's Law: "The current induced in a conductor as a result of its motion in a magnetic field is in a direction to oppose the motion which caused it."

The current through the conductor as a result of its downward motion sets up a CCW field around the conductor. This field is in the same direction as the fixed field below the conductor and opposite the fixed field above the conductor. The combination of these two fields produces a force in a direction opposite of the conductor's movement, and thus opposes conductor movement.

If the conductor forms one side of a coil used in a motor, the conductor motion is due to current through the conductor. This current sets up a CW field that interacts with the fixed field to force the conductor down. As the conductor moves down through the field, the EMF induced into the conductor is 180° out of phase with the voltage applied to the conductor. Since this induced EMF tends to reverse conductor movement, it is referred to as counter EMF or CEMF. Due to the 180° phase difference between the applied voltage and the CEMF, the total voltage available to send current through the conductor is equal to the applied voltage minus the CEMF.

The amount of current decrease depends upon two factors: the rate (motor speed) at which the armature cuts the magnetic field, and the strength of the magnetic field. Increasing CEMF which, in turn, decreases armature current. Thus, CEMF limits armature current to a safe value and, since CEMF varies with motor field strength and motor speed, it also effectively regulates armature current as these two factors change.

Exercises (435):

1. What does the term "neutral plane" mean when associated with DC motors?

2. How can torque in a motor be increased?

3. What keeps the current of a DC motor from becoming so high it would destroy the armature?

4. Name two ways you can increase CEMF.

436. Describe the construction features and operating principles of a basic series motor.

Series Motors. The series motor has its field winding (stator) connected in series with its armature; thus, any change in armature current is accompanied by a corresponding change in field strength. Due to the series connection, the field winding has few turns of heavy wire in order to carry the high-armature current. Series motors have two main characteristics: high starting torque and poor speed regulation. The large starting current results from the absence of the following: CEMF; the low opposition of the field winding; and the low resistance of the armature. As soon as the developed torque becomes great enough to overcome the friction and inertia of the armature and any load connected to the motor, the armature starts into motion and accelerates toward its normal running speed. If the armature is prevented from rotating, the large starting current will burn out the motor windings in a short period of time. Most motors, especially those putting out several horsepower, have a fuse or some other protective device in the armature circuit and normally use some method to reduce the large starting current.

After the initial start, armature current begins to decrease as an increasing CEMF is induced into the armature. However, this decrease in armature current also decreases motor field strength which, in turn, attempts to decrease the CEMF. Due to this action, the series motor continues to accelerate in an attempt to maintain CEMF and limit armature current to a safe value. If the motor is not connected to a load, it accelerates to a very high speed that may cause extensive motor damage. For this reason, series motors are never operated without a load; they are either geared or mechanically coupled to their load. In most small series motors (electric drills, for example), the gears load the motor sufficiently to prevent it from running away.

Series motors slow down as the load increases, and the slower armature rotation decreases CEMF. This results in an increase in armature current that then provides additional torque. The change in speed necessary to obtain the additional torque is an indication of the motor's speed regulation. A series motor, because its field strength depends upon armature current, requires a large variation in speed for a relatively small change in torque. The series motor's change in speed for a given increase or decrease in load is much greater than the change in speed that would occur if its field strength were constant.

The direction of rotation for a series motor may be changed by reversing current flow in a field winding or reversing current flow in the armature. Direction of rotation cannot be changed by reversing the power source leads, since this action would reverse current flow in both the armature and field winding. When both these currents are reversed, torque remains in the same direction and motor rotation remains unchanged.

A common method of causing one motor to operate in either direction uses two field windings. Current through one winding in series with the armature causes clockwise motor rotation; current through the other winding in series with the armature causes counterclockwise motor rotation. This type motor is often called a split-field series motor.

One advantage of the series motor over other types of motors is its ability to operate on either DC or AC excitation. When a series motor is constructed for use with both AC and DC, it is called a universal motor.

Exercises (436):

1. In a series motor, how are the field windings and armature connected?
2. What are the two main characteristics of a series motor?
3. Why should you never operate a series motor without a load?
4. What are the two ways we can change the direction of rotation of a series motor?
5. Briefly state how a split-field series motor works.

437. State the operating principles and characteristics of a basic shunt-type motor and compare its operation with the series motor.

Shunt Motors. A shunt motor has its field winding stator in parallel with the armature. Since the field winding is connected directly across line voltage, it is composed of many turns of fine wire. This type winding is necessary to maintain a high flux and to prevent overheating the field coils.

When the field winding is connected to the line voltage, the field current and field flux rise quickly to their full value. Armature current also rises rapidly since CEMF is zero when the armature is stationary. When the developed torque is great enough to overcome the friction and inertia of the armature and load, the armature starts into motion and CEMF proportional to motor speed is induced. The CEMF causes armature current to drop rapidly as the motor accelerates. Armature current becomes constant when motor speed becomes constant.

The field strength of the shunt motor remains essentially constant; therefore, its operating characteristics are quite different from those of the series motor. These characteristics are low starting torque and good speed regulation. The low starting torque does not mean the shunt motor cannot be started with a load. Instead, it indicates that if a series and shunt motor are of equivalent size and horsepower, the series motor produces the greater starting torque.

Good speed regulation makes the shunt motor adaptable to applications that require a fairly constant speed under varying load conditions. Unlike a series motor, the speed of a shunt motor must change only a small amount in order to develop a relatively large change in torque.

Due to the relatively large opposition of its field winding, the shunt motor cannot be used with AC. This large opposition, resulting from many turns of fine wire in the field winding, would cause field current to lag armature current by almost 90°. Assuming that a 90° lag is present, the motor's average torque would be zero. Direction of rotation for a shunt motor is changed in the same manner as in the series motor. Reversing current flow in either the armature or in the field coil changes direction or rotation.

Exercises (437):

1. In a shunt motor, how are the field windings and armature connected?

2. What are the operating characteristics of a shunt motor?

3. State whether each description applies to a series motor, or to a shunt motor:

   a. Low starting torque and good speed regulation.

   b. High starting torque and poor speed regulation.

   c. Never operate without a load.

   d. Cannot be used with AC.

   e. Operates on either DC or AC excitation.

438. State operating principles and characteristics of a basic compound-type motor and differentiate between the cumulative-compound and differential-compound motors.

Compound Motors. The constant speed characteristic of the shunt motor and the high-torque characteristic of the series motor are combined in a single motor by giving the motor two field windings: one in series with the armature and the other in shunt with the armature. This type of DC motor is a compound motor.

Considered as a shunt motor, the series field provides more torque as the load increases. When the load increases, the motor slows down; this increases armature current, boosting the strength of the series field winding. With more total interacting flux, torque increases and the motor regains its speed.

Considered as a series motor, the shunt field provides constant flux, and thus constant speed. The tendency of the series motor to run away with no load now has a counterforce of a constant flux field. Thus, motor speed limits itself to a reasonable value, as in the case of the regular shunt motors.

The series and shunt field windings can be arranged so that the field strength of one will be greater than the other. For example, the compound motor may be more like a series or more like a shunt motor. Motors that give preference to the high-torque characteristics are frequently series motors with a weak shunt field to prevent the motor from running away under no-load conditions. Sometimes such motors are referred to as series-shunt motors.

Other compound motors have the series characteristic of high-starting starting torque just to start the motor. Once it is up to running speed, a switch disconnects the series winding and the motor operates as a shunt motor.

Most compound motors have the series and shunt field windings wound in the same direction so they aid each other in generating the total magnetic flux. This is a cumulative-compound motor.

Differential-compound motors have the series and shunt field windings wound in opposite directions so they oppose each other in generating the total magnetic flux. The differential-compound motor does not have the good starting torque of the series motor, but it is more sensitive to load changes and has better speed regulation than the shunt motor.

The direction of rotation of a compound motor can be reversed by reversing the direction of the current in the armature or the field, but not both.

Exercises (438):

1. 1. What are the main characteristics of a compound motor?

2. What characteristic is the cumulative-compound motor usually designed to improve?

3. What effect will you have on the direction of rotation of a compound motor if you reverse the polarity of the power connections to the motor while it is running?

4. What is the main difference between cumulative-compound and differential-compound motors?

Inductance and Capacitance

YOU PREVIDUSLY learned what AC is, how it is generated, and some of its characteristics. We are now going to discuss some of the properties of electrical circuits that affect the constantly changing current encountered in AC circuits. We investigate inductors and inductance, and describe how inductance is used in transformers and saturable reactors. Last, we discuss the makeup and use of capacitors and how to figure capacitance.

4-1. Inductance

You have studied the effect of resistance on the constant current of DC. Now we are ready to look at a circuit property that opposes a change in current flow. We begin with a definition of inductance and then discuss the factors affecting inductance, inductance formulas, and the phase relationship of current to voltage in an inductive circuit.

439. Define the various types of inductance and identify the terms and symbols for each type.

Inductance in Electrical Circuits. We define inductance as a property of a circuit that opposes any change in current flow. All circuits have this property. The opposition, however, takes place only when there is a change in current flow. The inductance does not oppose current flow, it only opposes a change in current flow. Where current is constantly changing, as in an AC circuit, opposition caused by inductance is always present. The symbol for inductance is the capital letter "L".

Before we continue with our discussion of inductance, let's review CEMF of motors. In motors, CEMF is voltage induced in the armature, as the rotating armature coils cut through the magnetic lines of the field. This CEMF is directly proportional to the speed of the armature. In other words, CEMF is directly proportional to the number of lines of force that are cut per second. Earlier you learned that there are three basic requirements for inductance: a magnetic field, a conductor, and relative motion. Look at figure 4-1 and see how alternating current fulfills these three requirements.

In figure 4-1,A, you see a conductor with an alternating current applied from a generator. At time TO, in figure 4-1,B, the current waveform is at zero, representing no current flow in the conductor, and there is no magentic field. From TO to T1 the current is increasing and is flowing from A to B in the conductor shown in figure 4-1,A. This increase in current flow produces an expanding (or moving) magnetic field around the conductor, as indicated by the arrows in figure 4-1,C. We now have a conductor, a magnetic field, and the relative motion necessary for induction.

When the current decreases from maximum to zero (during th interval T1 to T2, (fig. 4-1,B), the magnetic field collapses and cuts the conductor in the opposite direction, as shown in figure 4-1,D. We again have a conductor, a magnetic field, and relative motion. The same sequence of events occurs during the interval T2 to T4, except that the current in the conductor flows from B to A in figure 4-1,A, and produces an opposite polarity of magnetic field, as shown in 4-1,E, and F. This causes the polarities of the induced voltage to be opposite. In all cases, the induced voltage opposes the change in current flow.

To increase the property of inductance, the conductor is formed into a loop or coil. Assume you have a conductor that forms 2 1/2 loops or turns. Current flow through one loop produces a magnetic field that encircles that one loop in one direction. As current increases, the magnetic field expands and cuts all the loops. The current in every loop affects all other loops. The field cutting other loops has the effect of increasing the opposition to a current change. When current is increasing, energy from the alternating current generator builds up the magnetic field. When the current is decreasing, the magnetic field collapses and returns its energy to the circuit.

Self-inductance. Let us review some of the other terms that you will encounter in dealing with inductance. First of all, we have CEMF that is induced into the conductor. This is self-induction. Self-induction is the process by which the magnetic field of conductor (circuit) induces a CEMF in the conductor (circuit) itself. The symbol for self-induction is the same as the symbol for inductance; that is, the letter "L."

Mutual induction. Another type of induction is mutual induction. Mutual induction is the action of inducing a voltage in one circuit by varying the current in some other circuit. Mutual inductance, then, is the common property of two associated electric circuits that determines, for a given rate of change of current in one of the circuits, the electromotive force induced in the other. The symbol for mutual induction is the letter "M."

To illustrate mutual induction, place two coils close to each other. Apply power to one coil with an AC generator and connect a voltmeter to the other coil. There is no physical connection between the two coils. As alternating current flows through one coil, it produces a magnetic field that is alternately expanding and collapsing. Each time the magnetic field builds up or collapses, it cuts across the other coil. Again, you have the three requirements for induction: a magnetic field, a conductor, and a relative motion. You can see that a voltage will be induced in the other coil. This voltage will have one polarity when the magnetic field is expanding and the opposite polarity when the same magnetic field is collapsing. This alternating voltage will

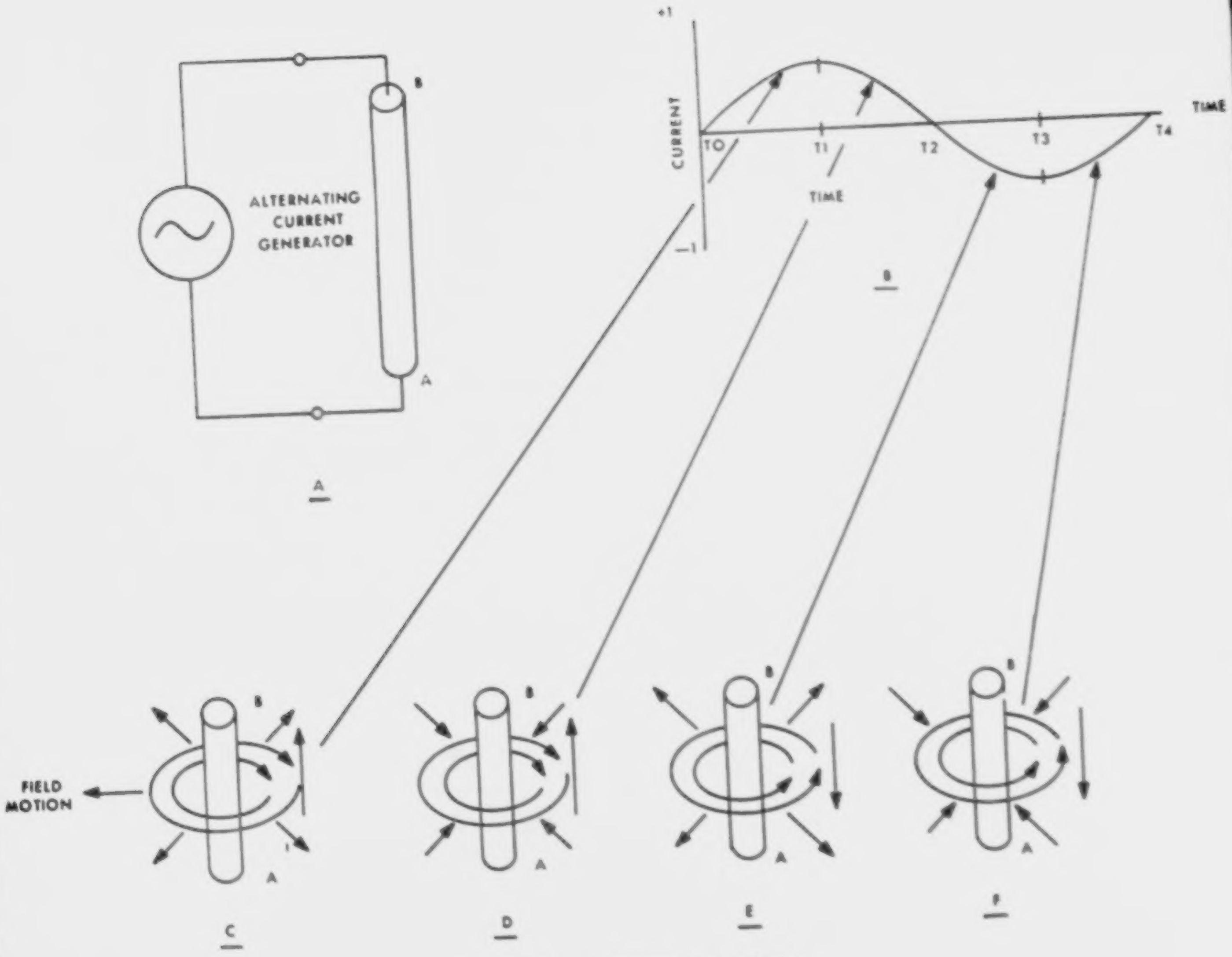

ALTERNATING CURRENT GENERATOR
B
A
A
+1
CURRENT
TIME
TIME
T0
T1
T2
T3
T4
−1
B
FIELD MOTION
B
A
C
B
A
D
B
A
E
B
A
F

Figure 4-1. Using an alternating field for induction.

cause current to flow through the voltmeter. The voltage induced into the second coil by a varying current in the first coil is an application of mutual induction.

The unit of measure for inductance is the "henry." A henry is the inductance in a circuit which induces an EMF of 1 volt when the current is changing at a rate of 1 ampere per second. The Government Printing Office symbol for henry is the capital letter "H."

Flux linkage. Flux linkage is the interlocking of magnetic lines of force, those magnetic lines around one coil or wire which link another coil or wire. The ratio of the flux lines (originating in one coil that cut a second coil) to the total number of lines developing around the first coil, gives you a new term called coefficient of coupling.

Exercises (439):

1. Define inductance and give its symbol.

2. Define mutual induction and give its symbol.

3. Define the term "henry" and give its symbol.

4. Define flux linkage.

440. List the factors that affect inductance values of a coil and compare the inductance of a soft iron core to that of an air core.

Factors Affecting Inductance. The four physical factors that affect the inductance of a single-layer coil are: the number of turns in a coil, the diameter of the coil, the coil length, and the type of material used for the core.

Number of turns in a coil. First, notice how the number of turns affects the inductance of a coil. Increasing the number of turns in the coil has the same effect as increasing the number of conductors in the field of a basic generator. In the basic generator, it increases the output; in a coil, it increases the CEMF. Doubling the number of turns increases the inductance of the coil by a factor of approximately four.

Coil diameter. The second factor is the coil diameter. Assume that you have two coils with the same number of turns and with the same diameter of conductors. The cores of each coil are the same length, but one core is much larger than the other. The larger core provides an easier path for the magnetic flux than the core with the smaller cross-sectional area. Again, this has the effect of increasing the strength of the magnetic field and, in turn, increasing the inductance of the coil. The inductance of a coil increases directly as the cross-sectional area of the core increases. Doubling the radius of a coil, therefore, increases the inductance by a factor of four.

Length of the coil. The third factor that affects the inductance of a coil is its length. This time assume that we have two coils with the same number of turns and the same diameter conductor. The core now has the same cross-sectional area, but one core is much longer than the other, and the turns of the conductor are spaced further apart. The coil with the longer core has few flux linkages, due to the space between turns, and, therefore, low inductance. The other coil has the same number of turns, but they are closely spaced, making a relatively short coil. This close spacing increases the flux linkage, increasing the inductance of the coil. A coil with twice the length of another will have half the inductance, or doubling the length of the coil will half its inductance.

Core material. The fourth physical factor is the core material used with the coil. For example, a soft iron magnetic core provides a better path for magnetic lines of force than a nonmagnetic core (such as air). The soft iron magnetic core's high permeability has less reluctance in the magnetic flux, resulting in more magnetic lines of force. This increase in the magnetic field increases the number of lines of force cutting each loop of the coil, thus increasing the inductance of the coil.

An additional factor is the type of coil winding used. Assume that we have a coil with close spacing and wound in layers. This has the effect of obtaining maximum flux linkage. Thus, the layer-wound coil has larger inductance values than the same size single-layer wound coils.

Exercises (440):

1. List the four primary physical factors that affect the inductance of a single-layer coil.

2. Which type of core, air or soft iron, has the least reluctance to inductance?

441. Given values of coil inductance for various circuit configurations, calculate total inductance.

Calculating Inductance. The unit of inductance (L) of a coil is the henry (H). A coil that develops a CEMF of 1 volt when the current is changing at the rate of 1 ampere per second has an inductance of one henry. From the above physical factors that affect the inductance of a coil, we can develop an expression that approximates the unit of inductance.

$$L = N^2\mu\frac{A}{l}$$

where

L = inductance

N = number of turns

A = cross − sectional area of the core

μ = permeability of the core material

l = length of coil

This expression must be multiplied by a constant to make a practical formula. This constant depends upon the:

- Units of linear measurement (inches or centimeters).
- Units of inductance (henries, millihenries, or microhenries).
- Coil construction (single or multilayered).
- Ratio of the length of the diameter of the coil.
- Percent of flux linkage.

Many times you will come across circuits with several inductors connected either in series or in parallel. The rules for computing the total inductance in a series or parallel inductance circuit are similar to the rules for computing total resistance in a series or parallel resistive circuit.

Visualize three coils connected in series in an AC circuit. The first coil introduces a certain amount of inductance, the second coil adds to this inductance, and finally the third coil adds to the total of the other two coils. To find the total inductance in a series circuit you must add the inductance of all the coils. So the formula for total inductance of coils connected in series is:

$$L_T = L_1 + L_2 + L_3 + \dots + L_n$$

What happens when three coils are in parallel? The coils provide three paths for current. The current that goes through the first coil is opposed only by the inductance of that coil. The same is true of the current going through the other two coils. The formula for computing the total inductance of a parallel circuit is therefore:

$$L_T = \frac{1}{\frac{1}{L_1} + \frac{1}{L_2} + \frac{1}{L_3} + \cdots \frac{1}{L_n}}$$

Exercises (441):

1. What is the total inductance of a circuit with coils of 15 henries, 6 henries, and 12 henries connected in series?

2. Compute the total inductance of a circuit with coils of 10 henries, 20 henries, and 30 henries connected in parallel.

3. What is the total inductance of a circuit containing three parallel legs? One leg is two series connected coils of 2 henries and 6 henries, one leg is 8 henries, and the other leg is 16 henries.

442. State the phase relationship between the voltages and current in a pure inductor, and identify factors that affect the voltage.

Voltage and Current Relationship in Inductors. We have mentioned that an inductor opposes a change in current flow. By knowing this fact, you can see that an inductor has very little effect on direct current. A sine wave of alternating current, however, is continually changing. This means that the magnetic field in an AC circuit is continually changing, generating a CEMF that continually opposes the change in current. Let's analyze the effects of an inductor in a circuit with an AC source.

Inductors connected to an alternating current source. In figure 4-2 we have an inductor connected to an AC source. The graph shows the relationship between the current (I) and the voltage (E) developed across an inductor with respect to time. The solid line of the graph represents the current across the inductor. This voltage (E) is actually a CEMF developed as the current's magnetic field expands and collapses. At time T0 in the graph, the initial rate of change and the CEMF are maximum. As the rate of change of current gradually decreases, from T0 to T1, the induced voltage decreases. At T1, the current stops increasing. We have zero rate of change, and the induced voltage is zero. As the current flow decreases (T1 to T2), its magnetic field collapses and the polarity of the voltage induced across the inductor reverses. Notice that at T1, with zero rate of change, E = 0. As the rate of change of current increases to maximum at T2, where even the direction of current flow changes, E = maximum with reversed polarity from T0 (−4 units).

Assume that current flow through the coil is from B to A, during time T0 to T2. The current through the coil forms an electromagnet that has one polarity. During the next half-cycle (T2 to T4), current flows from A to B and the electromagnet formed by the current has the opposite polarity. The electromagnet's polarity depends on current and has no relation to the voltage induced by the changing current.

Notice that maximum rate of change of current takes place when current passes through zero at T0, T2, and T4. As the current decreases to zero and reverses its direction, the induced voltage reaches its peak and then starts decreasing. When the rate of change of current decreases to zero, at T1 and T3, there is no change in flux and, therefore, zero voltage is induced in the coil.

In all cases, the amplitude of the induced voltage is determined by the rate of change of current flow. The polarity of the induced voltage is determined by two factors: the direction of current flow and whether it is increasing or decreasing. The induced voltage opposes any change in current flow. If current is increasing, induced

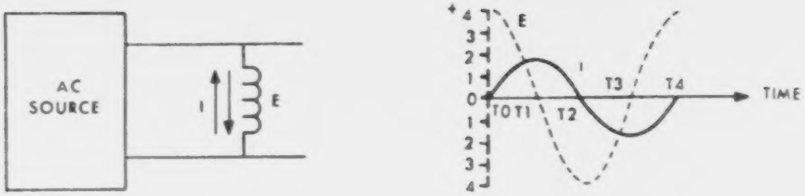


Figure 4-2. Inductor with a sine wave applied.

voltage opposes the increase; if current is decreasing, induced voltage opposes the decrease. Of special interest is the fact that for the sine wave of current, there is a sine wave of voltage. The current and voltage waveforms are 90° out of phase.

Inductors connected to an alternating voltage source. Now apply an AC voltage source to the inductor to see what happens. Imagine a circuit with an AC voltage source, conductors, and a coil, but *no opposition to current flow*, except from inductance. This is a circuit without resistance, a purely inductive circuit. The AC voltage applied to the inductance encounters an equal and opposite voltage induced in the coil, and zero current flows. As you know, this is a theoretical circuit and can only exist in practice; a real circuit must have some resistance. Therefore, assume the minimum amount of resistance. The CEMF still takes place, because of the inductance, but current lags the applied voltage by 90°.

Exercises (442):

1. When current flow is present in a coil, state what determines the amplitude of the voltage induced in the coil.

2. What determines the polarity of this induced voltage?

3. State the phase relationship of voltage and current through an inductor.

443. Define inductor power loss and state the methods for reducing power loss.

Inductor Power Losses. Power loss is defined as energy dissipated without accomplishing work. Let's discuss three types of power loss in inductors and methods used to reduce them. The first of the three types that we discuss is the copper loss.

Copper loss. Copper loss results from the resistance of the conductor used to wind the coil. This heat loss can be reduced by increasing the size of the conductor, thus reducing its resistance, or by using a material of lower resistance for the inductor. Normally, copper loss is reduced by increasing the conductor size. The only conductor material having less resistance than copper is silver.

Hysteresis loss. The second inductor loss is hysteresis loss. As you know, the core of a coil is magnetized whenever a current is flowing in the coil. If AC is applied to the coil, the core is magnetized first in one direction and then in the other direction. When a material is magnetized, the molecules of the material align themselves with the magnetic field. Every time the magnetic field reverses, the molecules realign themselves. This constant reversal of the molecules causes molecular friction, thereby producing heat called hysteresis loss. Hysteresis loss is reduced by using a material with a high permeabiltiy for the core. The higher the permeability of the material the less the molecular friction.

Eddy Loss. The third inductor loss is eddy currents. Eddy currents are currents which are induced in the core of the inductor. You remember our requirements for inducing a voltage, a conductor, a magenetic field, and relative motion. In this case, the core is the conductor that is cut by the expanding and collapsing fields of the coil, inducing current in it. Eddy currents cause excessive heat in a soft iron core.

Eddy currents are reduced by laminating the core. A laminated core is made up of thin sheets of metal, electrically insulated from one another. The insulation does not oppose the magnetic flux, but it does reduce the eddy currents by limiting the paths for current flow.

Exercises (443):

1. Define inductor power loss.

2. How can copper loss in the inductor be reduced?

3. How can you reduce inductor power loss caused by the molecular friction of the core?

4. Why does a laminated core reduce eddy current loss?

444. Define inductive reactance, identify its unit of measure and with given information, calculate inductive reactance.

Inductive Reactance. You learned that the current in a purely inductive circuit lags the voltage by 90°, because of the opposition to alternating current offered by inductance. The magnetic field expands and collapses; thus, it reacts and dissipates no power. For this reason, we call the opposition reactance and use the symbol X. Reactance of a coil, L, is inductive reactance, X_L, and is defined as the opposition to current flow offered by the inductance of a circuit. You can calculate the inductive reactance of a circuit by using the following formula:

$$X_L = 2\pi fl$$

where

X_L = inductive reactance in ohms (dissipates no power)
2π = 6.28
f = frequency in hertz
l = inductance in henries

As you can see by the formula, there are two variables that affect inductive reactance. They are: the inductance and the frequency of the circuit. You will find that since inductive reactance is opposition to current flow, we use the same unit of measure as we do for resistance. Inductive reactance X_L is measured in ohms.

Exercises (444):

1. Define inductive reactance.

2. What is the unit of measurement for inductive reactance?

3. Given the following information, calculate for X_L:

    a. 400 Hz 6 henries

    b. 6 kHz 3 millihenries

    c. 20,000 Hz 7 millihenries

4. The frequency applied to an inductive circuit changes from 60 Hz to 120 Hz. What happens to the inductive reactance of the circuit?

4-2. Transformers and Saturable Reactors

Now you are ready to learn how the principle of induction applies to two devices common throughout electronic circuits, the transformer and the saturable reactor. We will discuss transformer construction, the step-up and step-down turns ratios, transformer operation with loaded secondary windings, and types of transformers. Finally, you will learn fundamentals of using test equipment to check for opens and shorts in a transformer and to determine whether a transformer has a step-up or step-down turn ratio. We will conclude the section by discussing saturable reactors.

445. Name the parts of a transformer and identify one type.

Transformer construction. A transformer is a device that uses inductance to transfer electrical energy from one circuit or winding to another. A simple transformer consists of two coils of wire placed on some type of core. These coils are called windings. The winding that is connected to the source is the primary winding. The winding that supplies energy to the load is called the secondary winding. A transformer may have several secondary windings. Frequently, additional connections are made to a transformer winding between the end connections. These additional connections are called taps. A tap placed at the center of a winding is called a center tap.

Transformers use various materials for their cores. The air-core transformer is commonly used in circuits carrying radio-frequency energy. Radio-frequency transformers also use powdered iron, brass, and aluminum cores. Transformers used in low-frequency circuits require a core of low-reluctance magnetic material to concentrate the field about the windings. This type of transformer is called an iron-core transformer. Audio and power transformers are of the iron-core type. Iron cores are often fabricated from a number of thin silicon steel strips (laminations) covered with an insulating varnish.

Exercises (445):

1. Which winding is connected to the source voltage?

2. Which winding is connected to the load side of the transformer?

3. What type of core material do transformers used in low-frequency circuits require?

4. What is the transformer in exercise 3 called?

446. Very briefly explain "turns ratio," "coefficient of coupling," and "efficiency of transformers."

Turn Ratios. The ratio of the number of turns in the primary to the turns in the secondary is called the turns ratio. If an input of 10 volts at 60 Hz is applied to the primary winding and no load is connected to the secondary winding, the primary acts as a simple inductor. The current flowing in the primary will depend on the applied voltage (amplitude and frequency) and the inductive reactance of the primary. This current produces a magnetic field that cuts the primary and secondary as it expands and collapses. This produces a CEMF in the primary (self-inductance) nearly equal to the applied voltage, and it induces a voltage in the secondary (mutual inductance). The amplitude of the voltage induced into each turn of the secondary is identical to the CEMF produced in each turn of the primary.

When 10 volts is applied across 10 turns of the primary, a CEMF of nearly 1 volt per turn develops. A 2-turn secondary will then have an induced voltage of 2 volts (1 volt per turn). Thus, a turns ratio of 10 (primary) to 2 (secondary) has produced a step-down in voltage, from 10 volts (primary) to 2 volts (secondary), or 5 to 1. The transformer is described as having a step-down turns ratio.

With a transformer having a step-up turns ratio of 1:4, an input of 10 volts applied to the primary produces 40 volts in the secondary. The turns ratio equals the voltage ratio in all cases. We can express this as an equation:

$$\frac{N_p}{N_s} = \frac{E_p}{E_s}$$

where

N_p = number of turns in the primary
N_s = number of turns in the secondary
E_p = voltage of the primary
E_s = voltage of the secondary

The extent to which magnetic lines of the primary cut across the secondary is expressed as a "coefficient of coupling." If we say a transformer's coefficient of coupling is 1, this means that all of the magnetic lines of the primary link the secondary. That is, 100 percent of the flux lines produced by the primary winding cut the secondary winding. A coefficient of coupling of .9 indicates that 90 percent of the flux lines produced by the primary cut the secondary. A coefficient of coupling less than 1 reduces the voltage induced in the secondary.

Transformer Operation with Loaded Secondary. Up to now our discussion of transformer action has been with no load on the secondary; we considered induced voltage only. When a load is connected to the secondary winding of a transformer, current flows in the secondary. The magnetic field produced by current in the secondary interacts with the primary field. This interaction is truly mutual inductance, where both primary and secondary currents induce voltages. The magnetic field produced by secondary current is in direct opposition to the primary magnetic field and cancels some of it. field. This reduces CEMF, and, as a result, primary current increases to nearly reestablish the primary field. To summarize, as current increases (with increased load) in the secondary, primary current increases.

Total power available from a transformer secondary must come from the source which supplied the primary. Remember, a transformer does not generate power, it merely transfers power from a primary circuit to a secondary circuit. If the transformer is 100 percent efficient, total primary power equals secondary power.

If a 100Ω load is connected to the secondary of a transformer with step-up turns ratio of 1:10, 10 volts applied to the primary will produce 100 volts in the secondary. Current through the 100Ω load will be 1 amp. Power consumed in the load is (P = 1 × E) 100 wats. With 10 volts applied to the primary winding of 10Ω, the primary current is 10 amps. Applying the power formula (P = 1 × E) to the primary circuit yields 100 watts. Notice there is a step-up in voltage (1:10) and a step-down in current (10:1). Power supplied to the load comes from the source, and we have no losses in the coupling. This transformer is 100 percent efficient because output power equals input power.

Practical transformers, although highly efficient, are not perfect devices. They range from 80 to 98 percent efficient. Primary power must be slightly greater than secondary power to offset the decrease in efficiency. The losses associated with transformers are the same as the losses for inductors. Efficiency can be computed by dividing transformer output power by input power.

If a transformer has a step-down turns ratio of 10:1, 100 volts applied to the primary will induce 10 volts in the secondary. If we use a 10-ohm load connected to the secondary, we will have 1 amp of current. Power consumed by the load is 10 watts (P = I × E). Now the source must supply 10 watts of power. With 100 volts, the current needed to provide this power is .1 amp. Notice that we have a step-down in voltage but a step-up in current. The current is increased by the same ratio as the voltage decreased. Again, our calculations assume a 100 percent efficient transformer.

Exercises (446):

1. Define the term "turns ratio."

2. What type of ratio does a transformer have if, when we apply 10 volts to the primary, the voltage read across the secondary is 2 volts?

3. Write the equation used to express "the turns ratio of a transformer equals the voltage ratio."

4. Define the term "coefficient of coupling."

5. Assume that a transformer has a coefficient of coupling of .9. What does this mean?

6. What do we mean when we say that "a transformer is 100 percent efficient?"

7. State the voltage and current magnitude relationship of a transformer.

447. Name the four types of transformers, and give an identifying feature of the autotransformer.

Types of Transformers. In general, we have four types of transformers: autotransformers, power transformers, audio transformers, and RF transformers.

Autotransformers. The autotransformer is a special type of transformer. By definition, it is a transformer with a single winding (electrically) that is tapped. The whole winding may be used as the primary and part as a secondary (step-down) or part of the winding may be used as the primary (step-up). In all cases, a complete circuit exists between the primary and secondary windings.

Autotransformers are normally used in power circuits; however, they may be designed for audio or RF (radio frequency) use. Figure 4-3 shows the symbol for audio transformers and several hookups for different output voltages. The symbol for an RF autotransformer is the same except that it may not indicate an iron core. The RF autotransformer often has an air core.

Power transformers. Power transformers are often constructed with two or more secondary windings. Thus, one transformer can provide several voltage level outputs. The secondaries provide a wide selection of voltages and currents. Power transformers are designed to operate on the common powerline frequencies (50 to 60 Hz) and to handle relatively large amounts of power.

Audio transformers. The audio transformer resembles a power transformer in appearance, but it has several internal refinements. The core material is carefully selected, and special techniques are used to fabricate the windings. Audio transformers are designed to operate over the audio range of 20–20,000 Hz. Audio transformers are available with multiple primaries and/or secondaries.

RF transformers. This type of transformer is designed to operate in ranges from 10 kHz to 300,000 MHz.

Exercises (447):

1. Name the four types of transformers.

2. What is significant about the structure of ar autotransformer?

448. Given two hypothetical meter readings, identify the possible trouble in the transformer.

Troubleshooting Transformers. When you are troubleshooting a system, you may want to check a transformer for opens or shorts. You may also want to determine whether a transformer steps up or steps down the voltage. Let's first see how to check a transformer for an open or short.

You locate an open winding in a transformer by connecting an ohmmeter as shown in figure 4-4. In case of an open, the ohmmeter will read infinity. The reading on a good winding should be the resistance of the winding. Both the primary and secondary windings may be checked in this manner. (CAUTION: Make sure no power is applied to the ohmmeter and isolate the circuit component.)

PRIMARY	SECONDARY	
	STEP UP	STEP DOWN
1-2	1-3	2-3
1-3		1-2 2-3
2-3	1-3 1-2	

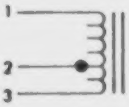


Figure 4–3. Chart and symbol for power and audio transformers.

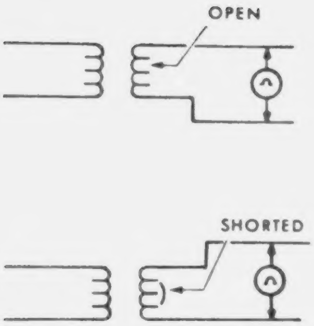


Figure 4-4. Troubleshooting open and shorted transformers.

You may also use an ohmmeter to check for a shorted winding as shown in figure 4-4. However, this method is not always accurate. For example, suppose a transformer winding had 500 turns and a resistance of 2 ohms and 5 turns were shorted out. This would reduce the resistance of the winding to 1.98 ohms—not enough difference to be read on an ohmmeter. The best way to check the transformer for shorted windings is to apply the rated input voltage to the primary and measure the output voltage of the secondary. If the output voltage is low, you can assume that the transformer has some shorted windings.

Exercises (448):

1. What would the probable trouble be if you read infinity on an ohmmeter that is placed across the secondary?

2. You have a transformer that you know as 2 to 1 ratio, but the voltage output measures low. What is the probable cause?

449. State the two methods for determining if a transformer provides a step-up or step-down effect.

Method for Determining Step-Up or Step-Down Operation. Earlier in this lesson you learned that the turns ratio determined whether the voltage was stepped up or stepped down and by what amount. Assume we have a transformer and the primary has 110 volts applied. One secondary has a 5-volt output, while another secondary has a 330-volt output. Assuming a coefficient of coupling of 1.0, the turns ratio would be 22 to 1 for the 5-volt secondary and 1 to 3 for the 330-volt secondary. Further assume that the transformer has a 220-turn primary, 10-turn (5 volt) secondary. The 5-volt winding, since it has the least number of turns, will have the smallest resistance. The 330-volt secondary (with 660 turns) will have the largest resistance. This shows how you can use resistance readings to determine whether a transformer has a step-up or step-down turns ratio. In a step-down transformer, the resistance of the secondary is less than that of the primary. In a step-up transformer, the secondary will have the higher resistance.

Another way to determine whether a transformer has a step-up or step-down turns ratio is to apply a voltage to the primary and measure the output of the secondary. When checking a transformer in this manner, be sure that you do not apply voltages that exceed the rating of the transformer or of the meter. Assume there is a transformer with 10 volts applied to the primary and a voltmeter reading of 2 volts across the secondary, indicating a 5 to 1 step-down transformer. The windings of most standard transformers are color coded to indicate the output voltage.

Exercises (449):

1. Summarize two ways to tell whether a transformer is a step-up or step-down?

450. Name and explain the magnetic variables that affect reactors.

Variables in Magnetic Circuits. The transformer principles we have just discussed are used in saturable reactors. However, let's examine some additional variables in the reactor circuit created by a transformer winding. In an electrical circuit, voltage and current are the basic electrical variables. In the magnetic circuit, the magnetic variables are magnetomotive force (MMF) and flux. Magnetomotive force is the basic magnetic potential or pressure; it is the force necessary to create a magnetic field. MMF is determined by the number of turns of a coil times the current flow, often referred to as ampere-turns (NI) of a coil. If 3 amperes of current flow through three turns of wire, the MMF is 9 ampere-turns.

A second variable is flux. The flux of a magnetic circuit is the total number of lines of magnetism in the magnetic circuit. Flux compares with current in an electrical circuit. Just as current increases with voltage when resistance remains constant, the number of flux lines increases as the MMF increases, if the flux path remains fixed.

A third variable of a magnetic circuit is reluctance. Reluctance (R) opposes the increase of magnetic flux within the coil. If the reluctance increases, the magnetic flux decreases when the magnetomotive force remains constant. The reluctance of a magnetic circuit is directly proportional to the length and inversely proportional to the permeability and cross-sectional area of the magnetic path.

The permeability of any material may be expressed by the following ratio:

$$\mu = \frac{\text{B (flux density)}}{\text{H (magnetizing force)}}$$

This ratio is often referred to as the B–H ratio, and it is used as a basis for selecting core materials for saturable reactors. Core materials used in saturable reactor circuits can produce high values of flux density (B), with low values of magnetizing force (H). H is directly proportional to MMF and is the magnetic potential drop per unit length of a core, which compares to the voltage drop per unit length in the electrical circuit. Any change in the ampere-turns of a coil will cause a proportional change in magnetizing force H.

You know that in a given electromagnet (coil), as the magnetizing force increases, flux increases. We can chart this as shown in figure 4-5. Notice that with no air-core coil the flux density (B) increases in a straight line, at a constant rate, with an increase in magnetizing force. The high reluctance and the low permeability of air in the magnetic circuit requires a high magnetizing force to cause many flux lines. Quite the contrary when we have an iron-core coil—the ratio of B to H in figure 4-5,B, is now a complex curve. Notice that the chart is divided into three sections; unsaturated region, transition region, and saturated region. Also notice the instep and knee section magnetizing force is rearranging the molecules in the iron core. The flux density increases rather slowly during this time. However, after the knee area is passed, the flux density increases rapidly as the magnetizing force increases. During the transition time, most of the last few molecules are being rearranged, causing the increase of flux density to level off. After this point, the core is saturated and the flux density remains relatively constant as the magnetizing force is further increased.

Figure 4-5 uses direct current as the magnetizing force. Alternating current requires a further look at what happens in an electromagnet. Recall that the sine wave of current reaches a peak amount in one direction, decreased to zero, and then flows in the opposite direction. Refer to figure 4-6,A, for a study of AC applied to an air-core coil. Applied AC increases to its peak value and magnetizes the coil to point a. As current decreases to zero and reverses direction, magnetizing force and flux density decrease back to zero and reverse direction to point d in figure 4-6,A.

With an iron-core coil, however, we have a curved line. As the magnetizing force reaches its first peak value at point a in figure 4-6,B, the iron core reaches maximum flux density at point a. As the magnetizing force decreases to zero, magnetic strength also decreases, but a "residual" magnetism stays in the core. When the magnetizing force is zero, the flux density of the residual magnetism is at point b.

When the magnetizing force is applied in the opposite direction, H must reach point c before flux density returns to zero. The magnetizing force required to cancel the residual magnetism is called coercive force. A coercive force from point o to point c is needed to reduce the flux to zero. As H continues increasing to point d, the flux density increases to point d. The return of the magnetizing force to zero results in a reduction in flux but, as before, B does not return to zero. Flux density decreases to point 3, and a coercive force from point o to point f is needed to reduce the flux to zero. The plotted cycle of magnetization (a, b, c, d, e, f, a), shown in figure 4-6,B, is called a "hysteresis loop."

The general effect where flux density lags the magnetizing force is called hysteresis. Energy is lost becuase a portion of the magnetizing force is used to overcome the residual magnetism. The area within the hysteresis loop is proportional to the amount of work done against the residual magnetism of the core, and represents the power loss. The amount of loss involves the type of core material and the frequency of the magnetizing force. The ideal saturable alloy is that which remains saturated until the coercive force cancels and reverses direction of flux lines. Figure 4-7 shows the hysteresis loop for such a type of alloy core material.

The high degree of rectangularity of the loop shown in figure 4-7 shows that the core has a quick transition between positive and negative saturation. The narrowness of the loop shows the small amount of coercive force needed to overcome the residual magnetism; it also indicates that a small magnetizing force can cause core saturation. The ideal hysteresis loop for saturable reactors is rectangular in shape and very narrow in width.

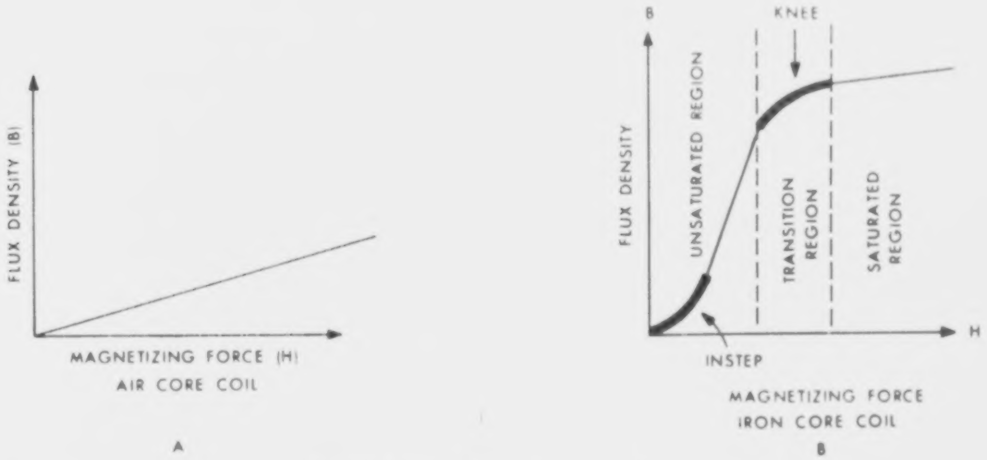


Figure 4-5. Uses of DC as a magnetizing force.

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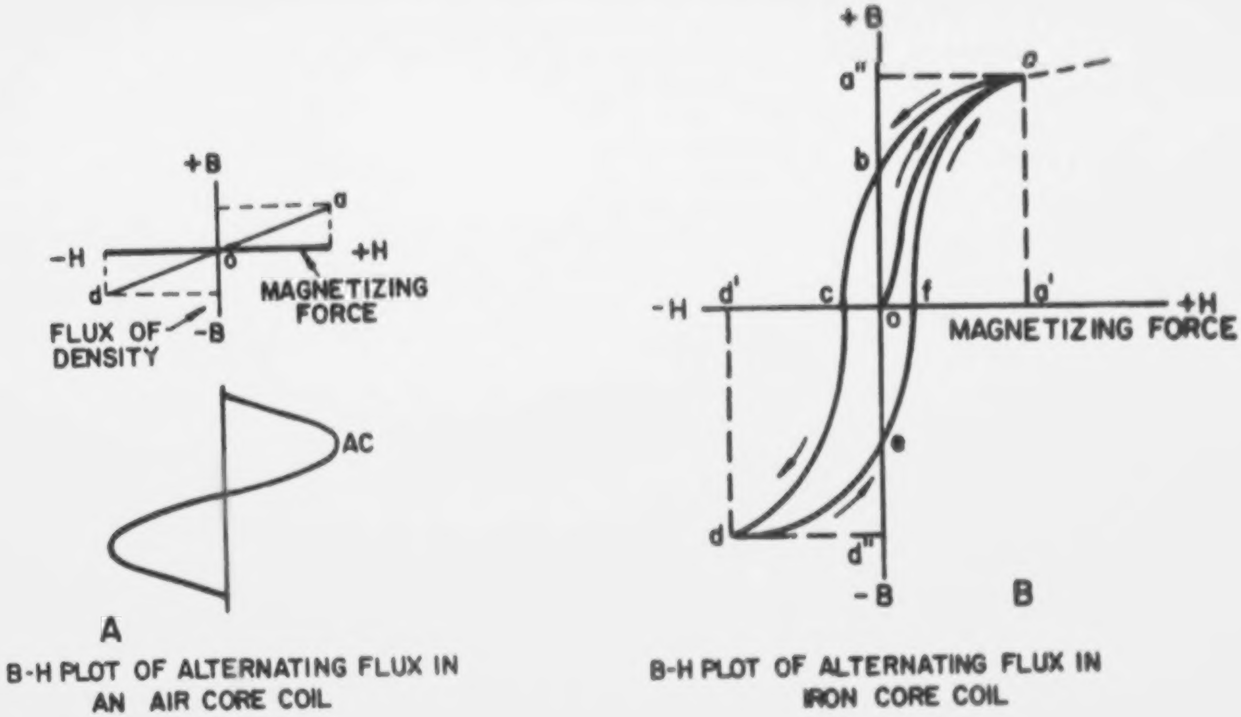


B-H PLOT OF ALTERNATING FLUX IN AN AIR CORE COIL

B-H PLOT OF ALTERNATING FLUX IN IRON CORE COIL

CI 76-180
0-4b

Figure 4-6. Use of AC as a magnetizing force.

Exercises (450):

1. Name the three magnetic variables.

2. Explain the B–H ratio and write the ratio expression.

3. Refer to figure 4-5 of your text. Explain the significance of the instep.

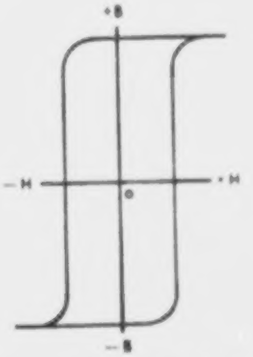


Figure 4-7. Hysteresis loop for special type of alloy core.

4. Briefly explain what causes a hysteresis loop.

5. Describe the ideal hysteresis loop for a saturable reactor.

451. State the function, operation, and construction of saturable reactors.

Operation of a Saturable Reactor. Early shapes of the saturable reactor core were very similar to that of the conventional transformer. The transformer core is still used in some applications but is often replaced by the ring-shaped or toroidal core. Figure 4-8,A, shows a simple saturable reactor circuit. A toroidal coil reactor in series with a load resistor (RL) is driven by a sinusoidal AC line voltage.

The saturable reactor functions as a synchronous switch because the impedance of the reactor changes abruptly from a high impedance to a low impedance during each half-cycle of applied line voltage. The point at which the impedance change occurs is determined by the core characteristics. When the core of the reactor is unsaturated,

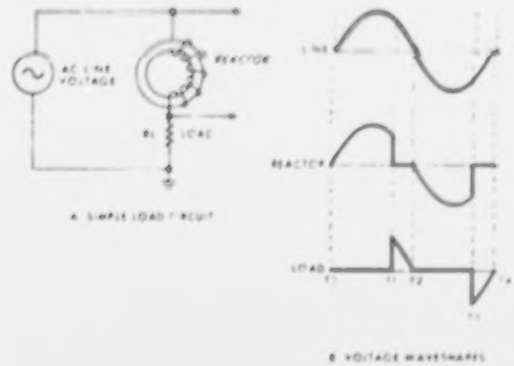


Figure 4-8. Simple saturable reactor circuit.

the impedance of the reactor is very high compared to the load impedance. During this time, the reactor acts as an open switch (consequently, very little power reaches the load from the AC line). When the core of the reactor becomes saturated, the impedance of the reactor drops abruptly from a high value to a low value. At this time, the reactor acts as a closed switch and the full line voltage is impressed across the load resistance. The change from one impedance level to the other is rapid, and it is repeated with every half-cycle of the applied line voltage.

Figure 4-8,B, shows the voltage wave shapes developed across the load resistor and the reactor for one cycle of applied line voltage. In this example, the line voltage is considered to have sufficient amplitude to drive the core into saturation on each half-cycle. At time T0, line voltage is applied. As the voltage increases in the positive direction, magnetizing force increases, and flux density in the core increases to saturation. The current flow through the load between T0 and T1 is very low. The amplitude of current at this time is determined by the width of the hysteresis loop; this current and the number of turns in the coil (NI) determine the magnetizing force (H). During this interval, the impedance of the reactor is very high compared to the resistance of the load. As a result, most of the line voltage is dropped across the reactor.

At T1, flux density reaches maximum and the core saturates. The high impedance of the reactor drops to a low value, and a heavy surge of current causes an instantaneous rise in voltage across the load resistor. During the time interval between T1 and T2, useful power is delivered to the load from the line voltage supply.

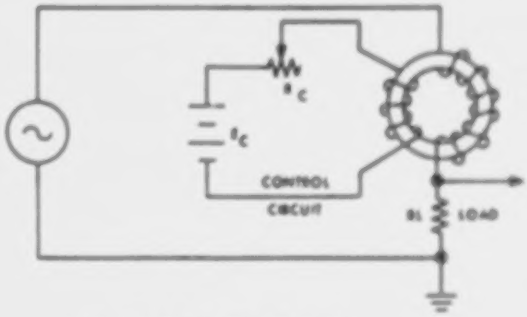
At T2, line voltage reverses polarity and current flow changes direction. The impedance of the reactor is once again high. A low value of magnetizing current flows, as in the positive half-cycle. Because of the high impedance of the reactor compared to the low impedance of the load, most of the line voltage is dropped across the reactor between T2 and T3. At T3, flux density reaches its maximum value, and the core again becomes saturated. At this instant, the impedance of the reactor drops rapidly from a high value to a low value. The heavy surge of current again causes nearly all of the voltage to appear across the load. For the remainder of this half-cycle, useful power is delivered to the load. At T4, the polarity of the line voltage reverses, and the action just described repeats as it does with every cycle.

When the core is saturated and no additional flux density is possible, further increase in magnetizing forces causes no change in flux. Thus, no CEMF or opposition resulting from a change in flux takes place. At this time, the only opposition of the reactor coil is its DC resistance, thus the load received useful power.

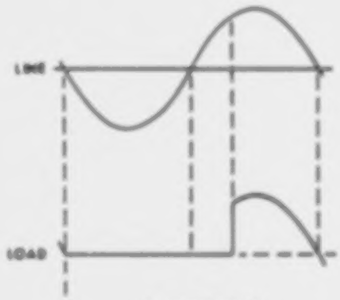
Another circuit must be added to figure 4-8,A, to establish control over the time during which core saturation occurs. Refer to figure 4-9,A. Notice that a DC source (E_c) is connected through the control circuit to a control winding on the toroidal coil. Adjusting resistor R_c controls the core the instant saturation occurs and, thus, controls the average power delivered to the load (RL). A small power source controls a large power source; this demonstrates amplifier action.

The voltage wave shape developed across the load resistance in one cycle of line voltage is shown in figure 4-9,B. When AC line voltage is applied, notice that the coil reaches saturation on the positive swing but not on the negative swing. Thus, the AC circuit has high impedance for all of the cycle except that positive portion.

The DC control circuit establishes control over the time that the reactor is saturated. If the control current is



A. SATURABLE REACTOR CIRCUIT



B. WAVESHAPES

Figure 4-9. Saturable reactor with a DC control.

increased, core saturation occurs sooner. This causes the time reference T0 to move toward T1, the core saturates for a longer period of time, and the average current delivered to the load increases. If the control current is decreased, the time reference T1 is moved toward T2, and the core is saturated a shorter period of time. A decrease in control current results in less current being delivered to the load. The time at which the core becomes saturated is set by the control current, which, in turn, determines the output of the saturable reactor. The basic principles of saturation control are the same for all saturable reactors. The only difference that might exist is the arrangement of the control circuit.

The advantage of a saturable reactor is that it is simple, rugged, and reliable. It can drive many loads and handle large quantities of power with good efficiency.

Transformer action occurs between the load coil and the control coil. This transformer action lowers the efficiency of the circuit. The saturable reactor, shown in figure 4-9, is designed with a very high impedance in the control circuit. The purpose of the high impedance is to reduce control-circuit currents induced from the load coil. This keeps the impedance of the reactor high and load power low when the reactor is unsaturated. If the impedance of the control circuit is low, a large current is induced from the load coil, which causes load current to be large prior to core saturation. This seriously reduces the gain of the saturable reactor.

There are other methods used to reduce or, in some cases, practically eliminate the induced currents from the load coil. One method is to use an iron-core choke coil in the control circuit. The purpose of the choke coil is to present a high impedance to alternating currents so that the voltage induced from the load coil into the control coil produces only small circulating currents in the control circuit. Another way is to use two separate core elements, sometimes referred to as a twin-core arrangement. The control windings are series aiding, while the load windings are series opposing. The voltage induced into one of the control windings is cancelled by an equal but opposite voltage induced into the second control winding.

Exercises (451):

1. What is a saturable reactor and what does it do?

2. How can you control the output of a saturable reactor?

3. How can the transformer action between the load coil and control coil of a saturable reactor be reduced?

4-3. Capacitance

We have been studying inductance that opposes a change in current. In this section we discuss capacitance that opposes a change in voltage. With resistance and inductance, capacitance is the third useful property of electronic circuits. We begin with a study of the factors which affect capacitor operation and follow this with a discussion of the various types of capacitors. Then we discuss capacitive reactance and the method for determining capacitive reactance.

452. Name the electrical and physical factors that affect the operation of capacitors and state the unit of measure for capacitance.

Factors Affecting Capacitor Operation. A simplified diagram of a capacitor is shown in figure 4-10. To understand what happens within the capacitor, you must use the principles of electrostatics. In the uncharged condition, the atoms that make up the dielectric of a capacitor are in their normal or neutral state. That is, the electrons of each atom are revolving around their nucleus in normal orbital paths. To indicate this condition, figure 4-10 shows hree atoms (greatly enlarged) of the millions that make up the dielectric.

Electrical factor. When a voltage is applied to the capacitor, the plates become charged. Assuming the polarity as indicated in figure 4-10, electron flow from the applied voltage (E_a) is toward plate A and away from plate B.

The atoms within the dielectric now become affected by the repelling force of the field. The electrostatic field places a strain on the atoms and their orbits become distorted. The electrons that are repelled by plate A and forced to orbit closer to plate B force electrons to leave plate B to return to E_a. Thus, plate A has a negative charge and B has a positive charge. The changes in the potential on plate A are passed on to plate B through the dielectric. The electrons do not move through the dielectric; the force exerted on one side is passed to the other without physical contact. (Some electrons may pass through, due to leakage and other causes, but we do not discuss these at this time.) When stress is placed on the dielectric, energy is stored in the form of orbital strain. The many thousands of dielectric atoms have their orbits distorted by the electrostatic field and they develop force (E_a) equal and opposite to the applied force (E_a). When this happens, we say the capacitor is charged and electron flow ceases. The charged capacitor thus offers infinite resistance to DC—it blocks DC.

Should the applied voltage be removed by opening the switch (fig. 4-10), the electrons on plate A would be

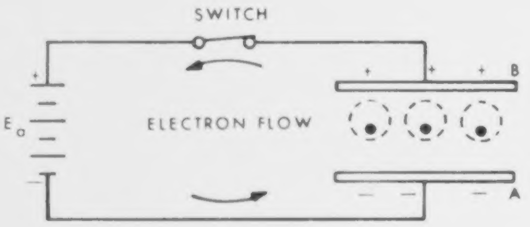


Figure 4–10. Electron flow in a capacitor circuit.

trapped; the deficiency of electrons on plate B continues; and the electrons of the dielectric remain in a charged condition. The charge on the capacitor can be removed by completing a path for the electrons to flow from plate A to plate B. Then the capacitor can discharge, equalizing the difference of potential between the plates.

The amount of charge stored in a capacitor is directly proportional to the applied voltage and the capacity of the capacitor. In other words, for a given capacitor, the ratio of charge to the applied voltage is a measure of the capacitor action called capacitance (C). The unit of measure of capacitance is the farad. A farad is defined as the capacity of a capacitor to charge to one coulomb (6.28×10^{18} electrons) with a difference of 1 volt potential across the plates. The physical size to produce 1 farad is beyond practical use. The unit in practical use is one millionth or one million-millionth of a farad. The millionth part of the farad is called the microfarad (10^{-6} farads) and is abbreviated μf. One million-millionth of a farad is called a picofarad ((10^{-12})farads), abbreviated pf.

Physical factors. Three physical factors determine the capacitance of a capacitor; plate surface area, dielectric thickness or plate spacing, and dielectric material.

a. The plate surface area controls the number of free electrons available to enter and leave the capacitor when a voltage is applied. A large plate area will accept a larger charging current and maintain a larger charge potential. Therefore, the plate area has a direct bearing on the quantity of energy that can be applied or stored in the capacitor.

b. The dielectric thickness or spacing between the plates is inversely proportional to the capacitance of a capacitor. Increasing the distance between the plates decreases the force of the repelling electron and, therefore, decreases the amount of charge.

c. The dielectric material used in the construction of a capacitor determines the amount of voltage that may be applied and the quantity of energy stored. The dielectric materials have different atomic structures and present different quantities of atoms to the electrostatic field.

Working voltage. In addition to its measure of capacity, every capacitor has a working voltage rating. The amount of voltage that can be applied is determined by the dielectric material. The working voltage refers to the maximum DC value that can be applied to the capacitor continuously. A capacitor marked 600 VDC should be expected to withstand a continuous application of 600 VDC without damage to the capacitor.

Exercises (452):

1. When does a capacitor offer the maximum resistance to DC?

2. The amount of charge stored in a capacitor is directly porportional to what?

3. Name and define the unit of measure of capacitance.

4. What are the physical factors that determine the capacitance of a capacitor?

5. What is the "working voltage" rating, and on what physical factor is it based?

453. Name the classes of capacitors, and state the applications and characteristics of different type capacitors.

Types of Capacitors. In the construction of a capacitor, the size of the plates, spacing between the plates, and the dielectric materials not only determine the capacitance, they also determine the size and shape of the final product. Capacitors are divided into two principal classes: fixed and variable.

The fixed capacitors are used where a special value of capacitance is needed. These capacitors are usually named by the dielectric used. They include paper, oil, mica, electrolytic, and ceramic.

Variable capacitors are used in circuits where the capacitance requires adjustment. The variable types are named according to their function, and include tuning, trimmer, padder, and neutralizing capacitors. To indicate the value of capacitance, a color code similar to the one for resistors is used.

Paper capacitors. Paper capacitors are in common use because of their low cost and small size. The dielectric material is usually waxed paper that is a porous material; therefore, the paper capacitors are seldom used above 600 volts. The plates are long flat strips of tinfoil with paper placed between them as the dielectric. All three are rolled together into a cylinder. The completed cylinder is usually placed in a metal or cardboard container and sealed with wax or pitch to keep out the moisture. The outside foil is normally connected to the ground side of the circuit in order to create an electrostatic shield around the capacitor.

Oil capacitors. The oil capacitor is similar in construction to the paper type. The oil used for the dielectric has a much higher breakdown voltage and can handle medium high voltages (above 600 volts). Such capacitors are designed for high power and are usually found in transmitter circuits.

Mica capacitors. Mica capacitors have capacitance values between 5 and 50,000 picofarads (pf) and are used in circuits subjects to voltages up to 7500 volts. These low-capacitance components are used in high-frequency circuits. The high breakdown voltage of mica frequency circuits allows the high-frequency, high-voltage capacitors to be small in size compared to the same capacity and breakdown voltage of a paper capacitor.

Electrolytic capacitors. The electrolytic capacitor is encased in an aluminum can. The can is the negative terminal filled with an electrolyte (a liquid, nonmetallic conductor) that forms the negative plate. There is an aluminum post that acts as the positive plate. This post is covered with an oxide of film that acts as the dielectric. In this case, the capacitor type is not named by the type dielectric used. The electrolytic capacitor has a definite polarity and is used only in DC circuits. The reason for this is that if the current were reversed, the oxide coating on the positive plate would break down and current would flow through the capacitor until oxide formed on the negative plate.

Electrolytic capacitors are constructed for AC operation by effectively connecting two units back to back. The plates of such a capacitor have previously formed oxide films. The AC electrolytic capacitor is designed to present an insulation dielectric to both polarities; this design is used for starting AC motors, where the capacitor creates a phase shift for starting.

To overcome the disadvantage of the wet-electrolytic capacitor, a dry electrolytic was developed. The construction of this type uses two flexible aluminum sheets separated by a jelly-like electrolyte fixed to the separating gauze or paper. The method of construction is similar to that used for paper capacitors. The electrolytic capacitors are made in single and multiunit sections; this puts more than one capacitance value in one container.

Electrolytic capacitors are generally found in low-voltage power supplies. The case usually shows the polarity for connecting it in a circuit. In operating conditions, they handle low frequencies, relatively high power, and voltages up to 600 volts. Another disadvantage of the electrolytic capacitor is the high power loss. A good electrolytic capacitor will constantly show a DC resistance of little more than 1 megohm, compared to the minimum of 200 megohms of a good paper capacitor of equal value.

Ceramic capacitors. With the development of higher frequencies used in communications and television, there came a need for small capacitors with a high dielectric strength. The ceramic capacitor was designed to fill these needs. Ceramic capacitors range from .5 pf to .01 f and can be used in low-power, high-voltage circuits (up to 30,000 volts). They are extensively used in television high-voltage power supplies. The construction is quite simple: a hollow ceramic cylinder is coated inside and out with silver paint. Contacts to the coatings are placed at each end of the cylinder. The silver conductors are separated from each other by the ceramic cylinder. The finished capacitor is quite small physically and, because of its size, shape, and coloring, it is sometimes mistaken for a resistor.

Variable capacitors. Variable capacitors are used for low, medium, and high frequencies. The low-frequency values range from 250 to 500 picofarads (pf). For higher frequencies, capacitors between 25 to 150 pf are used. For very high frequencies, values under 10 pf are used and referred to as microcapacitors.

In the variable capacitors that use air for a dielectric, the power and voltage in the circuit determines the capacitor's physical size. Air has a low breakdown voltage; therefore, the plates need to be spaced far apart if a large voltage is applied. The plates are connected in such a manner as to be able to pass next to each other without touching. One set of plates is on a rigid frame (stator); the other set is on a movable shaft (rotor). As the plates are rotated, the plate area producing the amount of capacitance can be increased or decreased. You probably have seen this type of capacitor in the tuning circuit of your radio.

The adjustable capacitor is another type of variable capacitor, designed to be set to a desired amount of capacitance and left that way. Adjustable capacitors are made with mica or ceramic dielectrics. The adjustable mica capacitor consists of a spring-metal plate separated from another plate by a thin mica strip. The spring-metal plate has a screw-type adjustment used to set the distance between the plates. Adjustable capacitors are in two groups: trimmers and padders. Trimmers are used in parallel with large variable capacitors and padders are used in series with them. The trimmer is sometimes indicated by a small T on the schematic diagram. The ceramic adjustable capacitors are similar to the mica in size and are also adjusted with a screwdriver. The plates of the ceramic capacitor are set in the ceramic material and are rated up to 500 VDC.

Exercises (453):

1. Name the two classes of capacitors.

2. Paper capacitors are seldom used where the voltage will exceed ____ volts.

3. What circuits are oil capacitors designed for?

4. In what circuits are mica capacitors normally used?

5. Which type of capacitor is designed primarily for DC circuits?

6. State the disadvantage of the electrolytic capacitor.

7. What type of capacitor is used in low-power, high-voltage (up to 30,000 volts) circuits?

8. What determines the physical size of a variable capacitor?

9. What are the two types of adjustable capacitors and how are they used?

454. State the relationship of current and voltage during capacitor operation.

Current and Voltage Phase Relationships. In figure 4-11,A, a capacitor is connected to an AC voltage source that develops a pure sine wave output. The graph in figure 4-11,B, shows the relationship between the voltage across the capacitor and the current that charges the capacitor. The solid line represents voltage (E_c) and the dotted line represents current (I_c). This current charges the capacitor so that, in turn, the capacitor has a voltage that opposes any change in voltage. At the instant voltage is applied by the AC source, the minimum charge across the capacitor (zero volts) allows maximum current I_c) to flow. This, in turn, allows the capacitor to charge. As the applied voltage increases from T1 to T2 in figure 4-11,B, the electrons accumulate on plate A and leave plate B of the capacitor in figure 4-11,A. This develops an opposing voltage, etc. When the peak positive potential on E_c reaches maximum at T2, (fig. 4-11,B), the capacitor's current decreases to zero. As the applied voltage decreases from its peak positive value to zero, the voltage across the capacitor decreases to zero, with maximum discharge current just as T3. From T3 to T4, the polarity of the applied voltage reverses the direction of current. This allows the capacitor to charge with a reverse polarity. From T4 to T6, the direction of capacitor current is just the opposite of current flow from T2 to T4.

An important thing for you to see at this point is that with a sine wave of voltage applied, the capacitor has its peak voltage charge when current is zero (T2 to T4). Also, with zero voltage on the capacitor, maximum rate of change of applied voltage causes maximum capacitor current. The capacitor current is directly proportional to the rate of change of voltage across the capacitor. However, capacitor current leads the capacitor voltage by 90°.

Look at the first 90° of the sine wave (T1 to T2) and try to realize that electrons must flow into one plate and away from the other plate of a capacitor before there can be a voltage across the capacitors. If you can understand this, then you can understand that capacitors store energy during voltage rise and then discharge energy as the applied voltage decreases. Keep in mind, though, that current does not flow through the capacitor; the charging and discharging of the two capacitor plates cause the current to flow into the circuit. Capacitors do not consume energy, they only store it. Therefore, a pure capacitor dissipates no power.

Exercises (454):

1. When is a capacitor said to be fully charged?

2. Assume that an AC sine wave voltage source is applied across a capacitor. During what part of the applied voltage cycle will current flow in the circuit be at minimum?

3. Does current lead or lag voltage in a capacitive circuit?

455. Define capacitive reactance, state what factors affect it and calculate it from given frequency and capacitance values.

Calculating Capacitive Reactance. The opposition of a capacitor to the flow of current is called capacitive reactance, X_c. Let's see what factors determine this reactance. Refer to figure 4-12,A, which shows a capacitor in series with an alternating-voltage charge (Q) to voltage (E). The capacitor stores an amount of energy equal to its

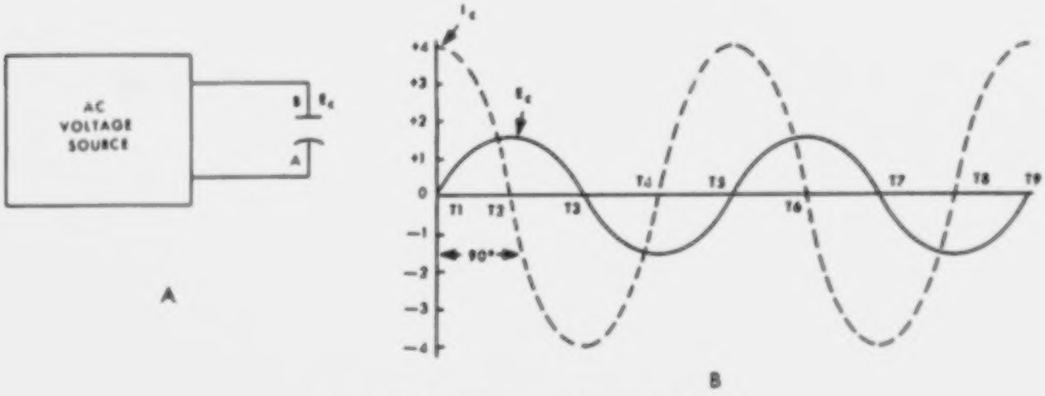


Figure 4-11. A capacitor connected across an AC source.

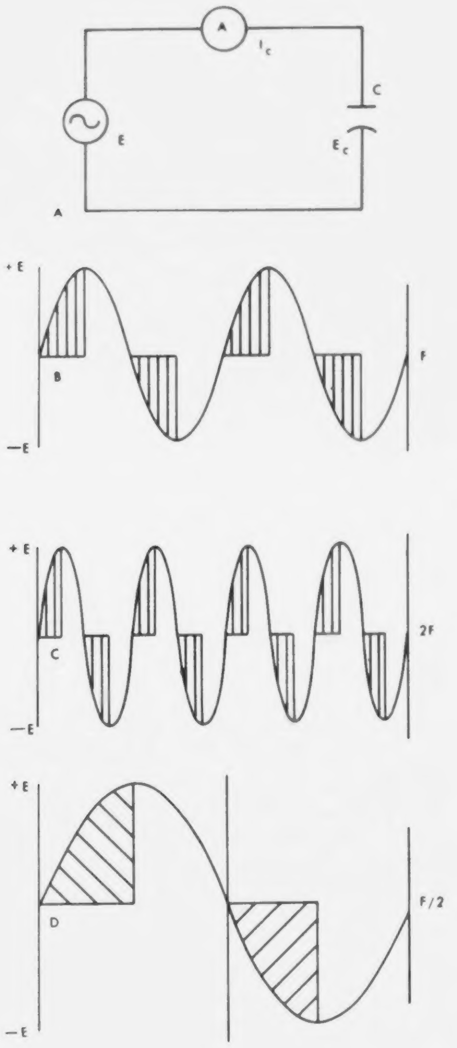


Figure 4−12. a capacitor connected in a series circuit.

capacity times the voltage (Q = CE). This amount of energy is stored two times (+E and -E) in one cycle of applied voltage (fig. 4-12,B). The time allowed for charging depends on the frequency $F = \frac{1}{T}$. If the frequency is doubled with no change in C or E, the same energy (Q) is stored in half the time. When the frequency is doubled (fig. 4-12,C), the capacitor charges to the peak voltage twice as many times, using twice the current. If the frequency is cut in half (fig. 4-12,D), then one-half the current flows because time is twice as long.

Capacitive reactance, then, depends on frequency. As frequency increases, current increases proving that the opposition (X_c) decreases. Capacitive reactance decreases as the frequency increases.

Capacitive reactance also depends on the size of the capacitor. As capacitance increases, the large capacitor allows more current flow to charge to the same voltage, so capacitive reactance decreases as the size of the capacitor increases.

We can now define capacitive reactance by the following formula:

$$X_c = \frac{1}{2\pi fC}$$

where:

X_c = capacitive reactance in ohms
2π = 6.28
f = frequency
C = capacitance in farads

Now we know that there are two variables which affect capacitive reactance. They are the capacitance and the frequency of the circuit. Since the formula for X_c always involved $\frac{1}{2\pi}$ which is $\frac{1}{6.28}$, we can save time later if we divide 6.28 into 1. We obtain .159, and the formula can now be written as:

$$X_c = \frac{.159}{fC}$$

Also, by transposing you can quickly change the formula to determine capacitance, C when X_c and f are known;

$$C = \frac{.159}{fX_c}$$

or we can solve for an unknown frequency when X_c and C are known:

$$F = \frac{.159}{CX_c}$$

Capacitors Used In Combinations. You will notice a similarity in the calculation of total capacitance to the calculation of total resistance. Capacitors add in parallel. This is easy to see when you recall that capacitance is directly proportional to plate surface area. If two or more capacitors are connected in parallel, you find the equivalent capacitance by adding their values.

$$C_{total} = C_1 + C_2 + C_3 + \dots C_N$$

Capacitors in series must be treated like resistors in parallel to determine the equivalent capacitance. In effect, the thickness of the dielectric material will increase and the distance between the plates will combine to produce an equivalent capacitor smaller than any one of the series capacitors.

With two capacitors, use the formula:

$$C_t = \frac{C_1 \times C_2}{C_1 + C_2}$$

For any number of series-connected capacitors of equal value, the total series capacitance is equal to their total value divided by the number of capacitors (as with equal resistors in parallel):

$$C_t = \frac{C}{N}$$

For more than two unequal capacitors in series:

$$C_t = \frac{1}{\frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3}}$$

In using the formulas for capacitors in series, the total capacitance is smaller than the smallest capacitor. The combination of capacitors in series results in an equivalent capacitor that has a smaller value and will withstand a higher circuit voltage than any one of the series capacitors.

Total Capacitive Reactance. You have been working with circuits that contain capacitors in series and parallel. You learned two basic principles about calculating equivalent capacitance when the capacitance (C) values are given. To find total capacitance of capacitors in parallel, add the individual capacitance values; in series, calculate using formulas as for resistors in parallel.

When the capacitive reactance (X_c) for a capacitor is known, the value is expressed in ohms. When circuits contain capacitors in series and parallel, treat any given capacitive reactance values as resistance. Remember that if the values are in ohms, treat them as you do resistors.

In a series circuit, the total capacitive reactance is expressed:

$$X_{c\,total} = X_{c_1} + X_{c_2} + X_{c_3} + \cdots \text{, etc.}$$

In a parallel branch, use the formulas for resistors in parallel: Three or more reactances:

$$X_{c_t} = \frac{1}{\frac{1}{X_{c_1}} + \frac{1}{X_{c_2}} + \frac{1}{X_{c_3}}}$$

Two reactances:

$$X_{c_t} = \frac{X_{c_1} X_{c_2}}{X_{c_1} + X_{c_2}}$$

Any number all the same value:

$$X_{c_t} = \frac{X_c}{N}$$

In solving for capacitor voltage, current, or reactance, use Ohm's law:

$$E_c = I_c X_c$$

$$I_c = \frac{E_c}{X_c}$$

$$X_c = \frac{E_c}{I_c}$$

Exercises (455):

1. Define capacitive reactance.

2. What factors affect capacitive reactance?

3. What is the unit of measure for capacitive reactance?

4. Solve for X_c in the following problems:

Frequency	Capacitor Value
a. 1 kHz	.5μf
b. 400 Hz	.01μf
c. 20 kHz	.05μf

5. In determining total value of capacitor combinations, what are the rules we observe?

6. Calculate for total capacitance in the following problems:

   a. Three .05 μf capacitors connected in parallel.

   b. Three .05 μf capacitors connected in series.

   c. Three parallel capacitor legs, one leg a .05 μf capacitor, the other two legs are .1 μf capacitors each.

d. Write the Ohm's law equations to solve for capacitor, voltage, and current, or capacitive reactance.

456. State the implications of given ohmmeter readings during a capacitor performance check.

Troubleshooting. Now, consider how to determine whether a capacitor is good, open or shorted. The ohmmeter has an internal battery that supplies the voltage for checking capacitors. Before connecting the ohmmeter, set it on the highest range. Make sure the capacitor is disconnected from a circuit and discharged. Then use the ohmmeter as if checking for resistance. When you connect the meter across a capacitor, the meter pointer will deflect momentarily as the capacitor accepts the charge. The amount of meter movement depends on the value of the capacitor being checked. If the pointer deflects momentarily and then drops back to infinity, the capacitor is good. With some capacitors it is difficult to detect this deflection. In this case, a practical check is to replace the capacitor with one that you know is good. No momentary deflection at all indicates an open. If the ohmmeter connected across the capacitor shows a steady resistive indication, the capacitor is leaky or shorted.

Exercises (456):

1. In checking a capacitor with an ohmmeter, you get a momentary meter deflection and then a reading of infinity. What, if anything, is probably wrong with the capacitor?

2. In checking a capacitor with an ohmmeter, you notice no momentary deflection. What condition does this indicate?

AC Circuits

DURING YOUR work on electronic systems, you will be involved with many AC electronic circuits containing various combinations of resistors, capacitors, and inductors. These combinations are used as resonant circuits, coupling circuits, and transient circuits. Before studying the function of these specific circuits, you need to know how resistors, capacitors, and inductors react when installed in combination with each other.

In this chapter, we discuss series resistor-capacitor (RC) circuits, series resistor-inductor (RL) circuits, and resistor-inductor-capacitor (RCL) circuits. We follow with parallel RC, RL, and RCL circuits, and series and parallel resonant circuits. In the last section of the chapter, we discuss the methods of electrically coupling one circuit to another.

5-1. RC, RL, and RCL Circuits

This section will add to your knowledge of capacitors, resistors, and inductors as they apply to series and parallel RC, RL, and RCL circuits. You will see how these components affect the voltage and current relationships in AC series and parallel circuits.

457. State the phase relationships of voltage and current in purely resistive and purely capacitive circuits, and define the term "vector."

Phase Relationship of Voltage and Current. Voltage and current in a purely resistive circuit are in phase and can be shown graphically with two sine waves. The two sine waves pass through zero and reach their positive peaks together indicating the in-phase relationship. In any circuit, the current through a resistor is in phase with the voltage drop across the resistor.

In an AC circuit containing only capacitance, capacitor voltage (E_c) lags capacitor current (I_c) by 90°, thus current which causes a voltage across a capacitor is 90° ahead of the voltage it develops.

Figure 5-1 shows a series circuit containing both resistance and capacitance. In this circuit, current has one path; thus, the resistor and capacitor have the same current flow. To show phase relationship in this circuit, a phase diagram for the resistor and capacitor must be combined, using current as the reference. The voltage (E_R) across the resistor (R) is in phase with the current (I) and the voltage (E_c) across the capacitor lags the current by 90°, as shown in the right-hand portion of figure 5-1. The instantaneous values of E_R and E_c add together to equal the applied voltage (E_a). We could plot another waveform representing the sum of these instantaneous values that would also show the phase relationship of E_a. This method of showing phase and amplitude is accurate but can become confusing and is time consuming. Fortunately, we can represent voltage, current, and other values with a simple graphic symbol called a vector.

Vector Representation of Phase Relationship. A vector is a line used to represent magnitude and direction. The length of the line denotes amplitude of the sine wave it represents. We place an arrowhead on one end and rotate the vector about a point at its tail (origin) to represent direction or phase angle. Since we can rotate the vector about its origin a full 360°, clockwise or counterclockwise, the phase relationship of any sine wave to a reference waveform can be shown. We can show a phase angle as leading (counterclockwise rotation) or lagging (clockwise rotation) the reference waveform by any value up to 360°.

How do you use vectors to find the resultant of two different amplitude and out-of-phase sine waves? To answer this question, let's again use the waveforms in figure 5-1. You first have to establish a reference vector to which the others can be compared. Since current is common to all parts of this series circuit, you can plot the voltages with reference to the current waveform. The conventional zero degree reference point for all vector diagrams is in the horizontal plane, so you can draw the current vector as shown in figure 5-2,A. The voltage across the resistor (E_R) is in phase with the current. Beginning at the same origin as the current vector, draw the E_R vector in the same plane and direction (fig. 5-2,B). Note that we have not attempted to assign any specific values for amplitudes at this time. We will get to that later. The voltage across the capacitor lags the current by 90°. To portray this, we again start at the same origin and rotate a vector 90° in the clockwise direction from the reference vector as shown in figure 5-2,C. The phase angle of this vector is −90°.

To determine the resultant or vector sum of the two voltage vectors, the applied voltage (E_a), you have to use a little trigonometry. Notice in figure 5-2,D that we have connected the heads of the voltage vectors with perpendicular dashed lines to form a parallelogram (in this case a square). We have also drawn an additional vector from the origin to bisect the square. This vector represents the vector sum of the voltage vectors or the applied voltage. To determine its length, which represents amplitude, you must use the Pythagorean theorem, which states that the square of the hypotenuse of a triangle is equal to the sum of the squares of its two sides. The E_a vector in figure 5-2,D, indeed, forms the hypotenuse of a triangle whose two sides are E_R and E_c. Therefore:

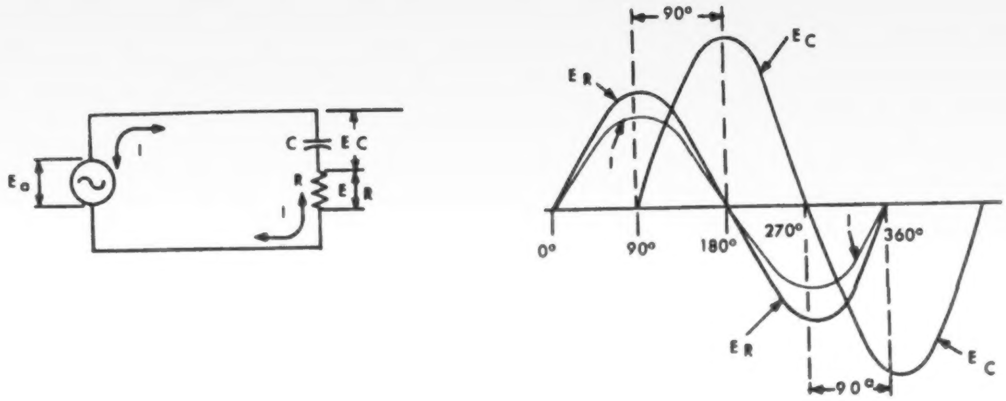


Figure 5–1. Series circuit containing resistance and capacitance.

$$E_a^2 = E_R^2 + E_c^2$$

or

$$E_a = \sqrt{E_R^2 + E_c^2}$$

Keep this application of the Pythagorean theorem in mind as we apply it in some practical examples shortly. If two vectors are both acting in the same direction, they are plotted with the tail of the second vector placed at the head of the first. The total length would represent the total value in that direction. We have shown how to determine the amplitude of a resultant vector, but what about its phase relation.

The angle θ (theta) between the E_a vector and the current vector in figure 5-2,D represents the phase angle between the applied voltage and the current waveforms of our circuit. This acute angle of a triangle can be determined by the following trigonometric equation for tangents:

$$\text{Tan } \theta = \frac{\text{side opposite}}{\text{side adjacent}}$$

For example, if the E_R vector is 6 units long and the E_c vector is 8 units long, you have:

$$\text{Tan } \theta = \frac{E_c}{E_R}$$

$$\text{Tan } \theta = \frac{8}{6} = 1.6667$$

$$\theta = 59°$$

Looking up 1.6667 in a table, you would find that it is the tangent of 59°. Since this angle was formed by rotating the vector clockwise from the reference vector, it is given a negative value:

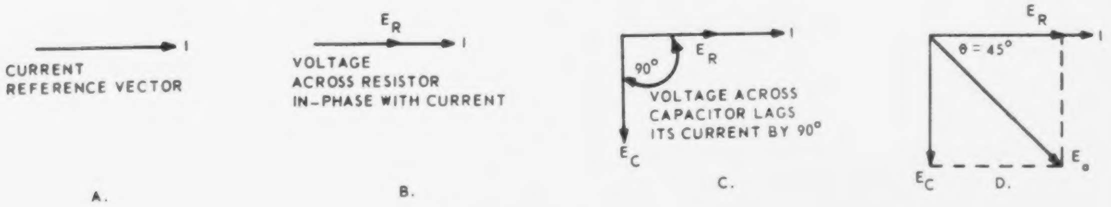
$$\theta = -59°$$

In the following discussions of AC circuits, we use vector diagrams to solve not only for voltage and current relationships but also for capacitive reactance, inductive reactance, and impedance (a term that represents the total opposition to current). To completely describe these vectors, we use a system called the polar form of vector notation. As an example, the E_c vector shown in figure 5–2,C, is expressed as $E_c \angle -90°$. E_c is the amplitude of the voltage and $\angle -90°$ represents the phase angle θ.

Exercises (457):

1. In a purely resistive circuit, what is the phase relationship of voltage and current?

2. In a purely capacitive circuit, what is the phase relationship of voltage and current?



I
CURRENT REFERENCE VECTOR
A.
ER
I
VOLTAGE ACROSS RESISTOR IN-PHASE WITH CURRENT
B.
I
ER
90°
VOLTAGE ACROSS CAPACITOR LAGS ITS CURRENT BY 90°
EC
C.
ER
I
θ = 45°
Ea
EC
D.

Figure 5–2. Vector diagram.

3. Define a vector as applied to AC circuits.

4. Assume that you have two horizontal vector lines plotted along the same line. What phase relationship would be represented by these two vectors?

458. State how a given combination of resistors, capacitors, and inductors affect an AC circuit.

Series RC Circuits. Now refer to figure 5-3,A. This portion of the figure shows a series with each other. The applied voltage (E_a) is 100 volts, the resistance (R) is 3K ohms, and the capacitance (X_c) is 4K ohms. To express the total impedance of the circuit, we draw an impedance vector diagram as shown in figure 5-3,B, with the 3K ohm resistor vector along the horizontal reference line and the 4K ohm capacitive reactance vector at −90° in relation to the resistance vector. The resistive and capacitive opposition are added vectorially to determine the total impedance. Thus, the impedance vector diagram has values of R, X_c, and Z. With resistance plotted at 0° and capacitive reactance at −90°, the impedance angle is negative also. The complete expression for impedance is $Z = 5K\Omega \angle -53.1^\circ$

Now, we can apply Ohm's law to find the current. If we use the applied voltage as our reference, we express the 100 volts at 0°.

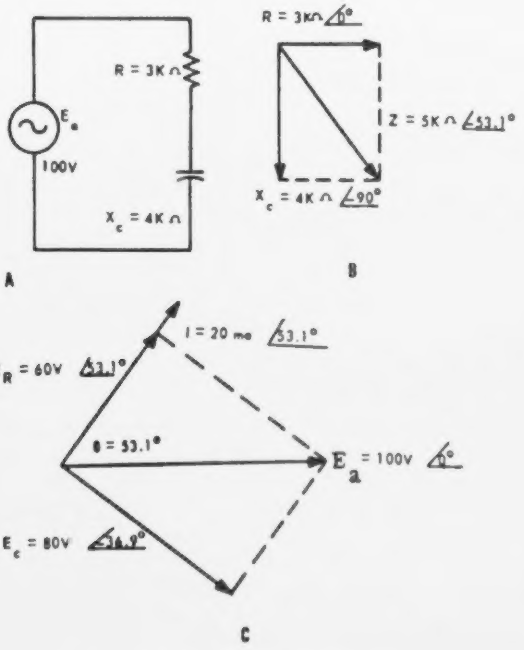


Figure 5–3. Resistive and capacitive circuit.

$$I_T = \frac{E}{Z} = \frac{100 \angle 0^\circ}{5K\Omega \angle -53.1^\circ} = 20 \text{ mA} \angle +53.1^\circ$$

Observe that we divide 5K ohms into 100 for 20 mA, and we subtract −53.1° from 0° to get +53.1°. This results in the current having a positive angle, proving that with a capacitive circuit, the current leads the applied voltage.

Now we can multiply the current times each impedance to find E_rE_c.

$$E_r = IR = 20mA \angle 53.1^\circ \times 3K\Omega \angle 0^\circ = 60V \angle 53.1^\circ$$

$$E_c = IX = 20mA \angle 53.1^\circ \times 4K\Omega \angle 90^\circ = 80V \angle -36.9^\circ$$

$$E_a = IZ = 20mA \angle 53.1^\circ \times 5K\Omega \angle -53.1^\circ = 100V \angle 0^\circ$$

Observe that we multiply current times impedance to get volts, and we add the angles algebraically.

Figure 5-3,C, shows a voltage vector diagram with voltage at the zero reference (horizontal) position. The voltage across the resistor is in phase with the current; the voltage across the capacitor is 90° behind the current; and the applied voltage is 53.1° behind the current. Notice that phase relationships of the voltage vector diagram are the same as the impedance vector diagram. When we multiply each impedance by the current, the diagram of figure 5-3,B, changes to that of figure 5-3,C.

Keep in mind that the applied sine wave voltage rotates through 360° with every cycle of applied voltage. The other voltage and current vectors in the diagram rotate at the same rate. For study purposes and constructing vector diagrams, we consider one point in time: either when the current is at 0° or when the voltage is at 0°.

Series RL Circuits. Inductance opposes a change in current. The expanding and collapsing magnetic field, caused by current through the inductor, cuts across conductors and induces a counter EMF that opposes the current-causing force. The current-causing force is, of course, the applied voltage (E_a). The opposing force (CEMF) is such that when a sine wave of voltage is applied the current through a pure inductance lags E_a by 90°.

Now consider a simple series circuit with a sine wave AC voltage (E_a) applied (see fig. 5-4). Notice that the circuit contains a resistor (R) and an inductor (L). We know that resistor voltage E_R and resistor current I are in phase. You also know that the voltage (E_L) across the coil leads the current through the coil by 90°. These phase relationships are shown in figure 5-4,B. At time T_2, the voltage (E_L) is maximum across the coil, but there isn't any current flow within the circuit. At time T_2+, the current has just begun to flow and increase to a maximum 90° later (T_4).

Notice that the current and voltage wave shapes across the resistor are in phase. This relationship continues as long as the circuit is in operation. Current lags the voltage across the inductor by 90°. The current in the coil is the same as the current in the resistor, and we can plot the voltage vectors with current as reference (see fig. 5-5). Figure 5-4,B, shows E_R larger than E_L; thus, we have plotted these values at right angles and drawn the rectangle as shown in figure 5-5.

Connecting points A and B gives the magnitude and direction of the applied voltage. The angle formed by E_a and I_t is the phase angle θ between the voltage E_a and I_t.

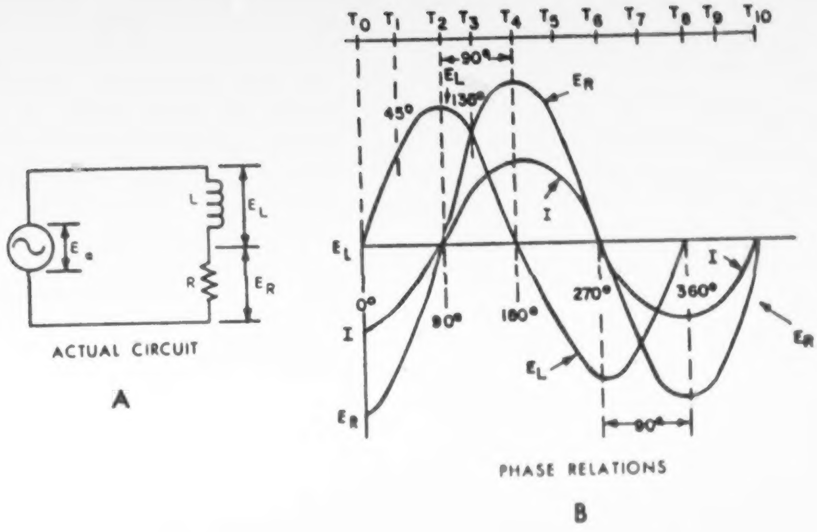


Figure 5–4. A series resistive inductive circuit.

Series RCL Circuits. The next circuit is a series RCL circuit shown in figure 5-6. This type circuit contains a resistor, a capacitor, and an inductor connected in series. The capacitive reactance causes the current to lead the voltage and the inductive reactance causes the current to lag to voltage. Thus, the two reactances are opposite in effect: X_L and X_c are 180° out of phase.

If L is in henries, to find X_L, we must use the formula $X_L = 2\pi fL$. If C is in farads, we must use the formula:

$$X_c = \frac{1}{2\pi fC}$$

You can see by the first formula that the reactance across an inductor increases as the frequency increases. The second formula indicates that the frequency increases. Now, let's draw a vector diagram for the impedance values (see fig. 5-7).

The resistance of the circuit is 12 ohms. This is shown as 12 units on the horizontal axis. As before, plot capacitive reactance at −90°, and inductive reactance at +90°, and we find that X_L and X_c are 180° out of phase with each other. The total reactance, therefore, is X_L - X_c, or 5 ohms of inductive reactance. This is shown as 5 units on the positive vertical axis, because X_L is larger than X_c. Next, by following the dashed lines, you can see that a parallelogram has been formed. The solid line drawn from point A to B is the vector sum and represents total opposition to current flow. Calculate for impedance by using the formula:

$$Z = \sqrt{R^2 + (X_L - X_c)^2}$$

In conclusion, the voltage drops across the capacitor and inductors are in opposite directions, or 180° out of phase. This is true in any series AC circuit containing X_l and X_c. If you place a voltmeter across both the capacitor and the inductor, you will read the difference in voltage.

Exercises (458):

1. Assume that you have an AC series circuit containing a resistor and capacitor. Give the relationship of current and voltage for both components.

2. Assume that you have an AC series circuit containing a resistor and inductor. Give the phase relationship of the current to the voltage for both components.

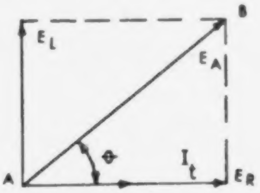


Figure 5–5. Vector diagram using current as a reference.

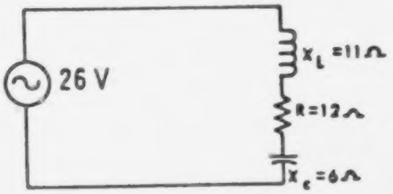


Figure 5–6. Series RCL circuit.

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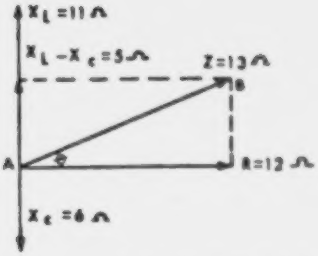

Figure 5–7. Vector diagram for impedance values.

3. Assume that you have an AC series circuit containing a capacitor, resistor, and inductor. Give the phase relationship between the voltage across the capacitor and the voltage across the inductor.

4. State how the reactance across inductors and capacitors is affected when frequency of the applied voltage increases.

459. Give the power output of series RC, RL, and RCL circuits.

Power in Series RC, RL, and RCL Circuits. In this lesson segment you will study the factors affecting power in series RC, RL, and RCL circuits. You should remember from previous lessions that power is defined as the "rate of doing work." Electrically, it is expressed in watts (joules per second) or in kilowatts (thousandths of watts).

In DC or purely resistive AC circuits, power is not a problem. Current is maximum; or in other words, current and voltage are in phase. Total power dissipated equals total voltage times total current. Maximum power is dissipated.

However, in reactive circuits, this may not be true. In a capacitive or inductive circuit, current is either leading or lagging the voltage. That is,.the current and voltage are out of phase, and dissipated power is not equal to total voltage times total current.

Figure 5-8 illustrates current, voltage, and power in an AC resistive circuit. The waveforms indicate instantaneous values. Em and Im donote maximum or peak values of voltage and current respectively. Note that voltage and current reach their maximum positive (above the zero line) and maximum negative (below the zero line) peaks together (in phase).

Notice that the power values are all positive. It's simple to understand when you remember algebraic multiplication. (A negative times a negative equals a positive.) Resistive power gives off heat or light, or is used in doing other "work." This is called true power, P_t.

In the case of resistive AC circuits, power can be found by the following formulas:

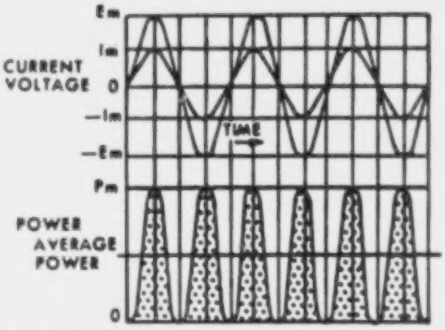

Figure 5–8. Current, voltage, and power in a resistive circuit.

$$P_t = IE$$

$$P_t = I^2R$$

$$P_t = \frac{E^2}{R}$$

Figure 5-8 shows Pm as the peak power when peak values of current and voltage are multiplied. Calculating with effective (RMS) values of voltage or current results in average power, P_{ave}.

Now look at figure 5-9. It represents current, voltage, and power in a purely capacitive circuit. The product of instantaneous values of the 90° out of phase values of current and voltage gives a waveform of positive and negative values. (Multiplying like signs give plus, and unlike signs give minus.) Changing every quarter cycle, figure 5-9 shows first positive current and negative current, then both are negative. You can see that the average power output in a purely capacitive circuit is zero (equal amounts above and below the zero reference line).

What is actually happening in a purely capacitive circuit is that the capacitor stores energy from the circuit in one-half alternation and returns it to the circuit on the next half

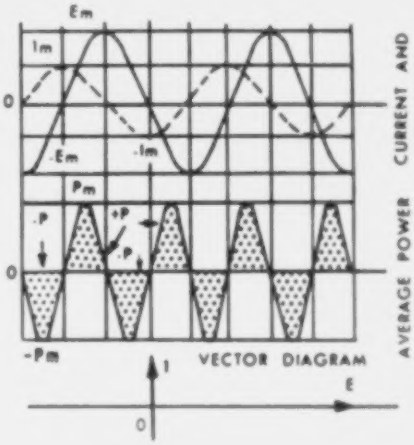

Figure 5–9. Current, voltage, and power in a capacitive circuit.

alternation. Consequently, no energy is actually expended, although there is an apparent expenditure of energy.

The same operation takes place in a purely inductive circuit. The coil stores energy on one-half alternation. The average power output of a purely inductive circuit is zero.

Figure 5-10 shows the current, voltage, and power relationships in a circuit containing resistance and inductance. (The same type of analysis could be applied to a resistance-capacitance circuit except that current leads the voltage across the capacitor.)

In figure 5-10 the voltage leads the current by an angle equal to theta θ. Since the voltage leads current by the phase angle, there is a period (equal to the phase angle), where the product of "e" and "i" is negative. This is the period of time when stored energy is returned to the circuit from the coil.

Since you already are familiar with how RC, RL, and RCL series circuits affect impedance values, voltage drops, currents, and phase angles, in a series AC circuit, you can now repeat these processes. If you have forgotten any of them, review them now before proceeding further.

Exercises (459):

1. What is the power output in a purely AC resistive circuit?

2. What is the average power output in a purely AC capacitive circuit?

3. What is the average power output in a purely AC inductive circuit?

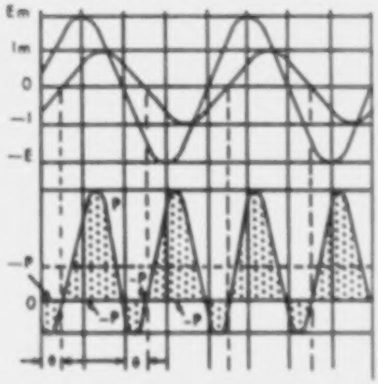

Figure 5-10. Current, voltage, and power in an RL circuit.

460. Briefly describe voltage and current application in parallel RC, RL, and RCL circuits and define "true" and "apparent" power.

Parallel RC, RL, and RCL Circuits. You learned many things in studying DC parallel circuits that you can apply to AC parallel circuits. You found that the applied voltage is common to all components of a simple parallel circuit and that the total current is the sum of the branch currents. These facts apply to AC parallel circuits, provided voltage and current phase relationships get proper consideration. Total current is not the arithmetic sum but, rather, the vector sum of the branch currents.

As you already know, current leads voltage across a capacitor by 90° and lags the voltage across a coil by 90°. Now we examine current, voltage, and power relationships in simple parallel RC, RL, and RCL circuits. First, you must learn how to solve for branch currents, total currents, total impedance, and phase angle (theta). Let's solve for these values in the parallel circuit illustrated in figure 5-11,A. In a circuit like this, the applied 60 volts is felt across the resistor; it is likewise felt across the capacitor. You can use Ohm's law to find I_R and I_c as follows:

$$I_R = \frac{E_R}{R} = \frac{60\angle 0^\circ}{3\angle 0^\circ} = 20\angle 0^\circ \text{ amps}$$

$$I_c = \frac{E_c}{X_c} = \frac{60\angle 0^\circ}{4\angle -90^\circ} = 15\angle 90^\circ \text{ amps}$$

You have 20 amps through the resistor and 15 amps through the capacitor. Now, observe the phase relationships of these currents. The total current is the vector sum of the individual branch currents. Look at the vectors that represent the current in our circuit in figure 5-11,B.

Current through the capacitor and current through the resistor are 90° out of phase. To add the vectors, complete a

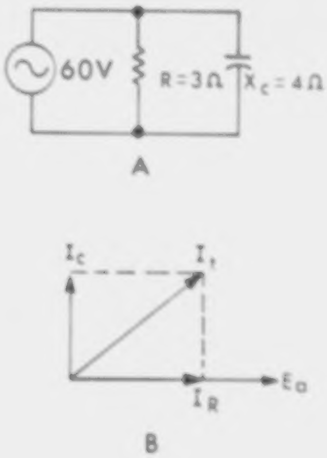

Figure 5-11. Parallel RC circuit and current vector.

parallelogram as shown by the dashed lines, and draw the resultant vector. Use the Pythagoren theorem to solve for the length of the resultant as follows:

$$I_t = \sqrt{I_2{}^2 + I_t{}^2}$$

$$I_t = \sqrt{(20)^2 + (15)^2}$$

$$I_t = 25 \text{ amps}$$

Use the law of tangents to find the current phase angle as follows:

$$\text{Tan } \theta = \frac{I_t}{I_R}$$

$$\text{Tan } \theta = \frac{15}{20} = .75$$

$$\theta = 36.9^\circ$$

The resultant of the currents (I_t) in this circuit is expressed as 25 $\angle 36.9^\circ$ amps.

To find total impedance, we can now use Ohm's law, substituting Z for R as follows:

$$Z = \frac{E_a}{I_t} = \frac{60 \angle 0^\circ}{25 \angle 36.9^\circ}$$

$$Z = 2.4 \angle -36.9^\circ \text{ ohms}$$

You should have noticed that I_t is larger than I_c or I_R but smaller than the arithmetic sum of I_c and I_R. Also total impedance is smaller than the smallest resistor or reactance (X_c or X_L) value in the circuit.

RL circuits are solved in a like manner. Refer to figure 5-12.

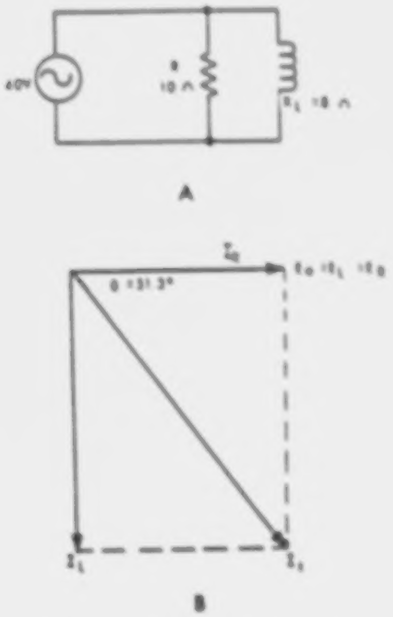

Figure 5-12. Parallel RL circuit and current vector.

$$I_R = \frac{E_a}{R} = \frac{40 \angle 0^\circ}{10 \angle 0^\circ} = 4 \angle 0^\circ \text{ amps}$$

$$I_L = \frac{E_a}{X_L} = \frac{40 \angle 0^\circ}{8 \angle 90^\circ} = 5 \angle -90^\circ \text{ amps}$$

Next, we will find the phase angle (θ) as follows:

$$\text{Tan } \theta = \frac{I_L}{I_R}$$

$$\text{Tan } \theta = \frac{5}{4} = 1.250$$

$$\theta = -51.3^\circ$$

Remember, current in an inductive circuit is 90° behind I_R and E_a. This is shown in the vector diagram in figure 5-12,B. The total current is the vector sum of I_L and I_R:

$$I_t = \sqrt{I_L{}^2 + I_R{}^2}$$

$$I_t = \sqrt{(5)^2 + (4)^2}$$

$$I_t = 6.4 \text{ amps}$$

The full notation for I_t is 6.4 −51.3°.

To solve for total impedance of the circuit shown in figure 5-12,A, use Ohm's law as follows:

$$Z = \frac{E_a}{I_t} = \frac{40 \angle 0^\circ}{6.4 \angle -51.3^\circ}$$

$$Z = 6.25 \quad 51.3^\circ$$

You can see that total impedance in the parallel RL circuit is less than the value of X_L or R.

Now you should be able to solve a circuit containing a coil, resistor, and capacitor (RCL circuit). Refer to figure 5-13. The work for this circuit is easy; find the branch current first by Ohm's law.

$$I_R = \frac{E_a}{R} = \frac{160 \angle 0^\circ}{160 \angle 0^\circ} = 1 \angle 0^\circ \text{ amps}$$

$$I_c = \frac{E_a}{X_c} = \frac{160 \quad 0^\circ}{80 \angle -90^\circ} = 2 \angle 90^\circ \text{ amps}$$

$$I_L = \frac{E_a}{X_L} = \frac{160 \angle 0^\circ}{320 \angle 90^\circ} = .5 \angle -90^\circ \text{ amps}$$

The vectors for this look like figure 5-13,B. Total current for this circuit is solved as follows:

$$I_t = \sqrt{I_R{}^2 + (I_c - I_L)^2}$$

$$I_t = \sqrt{(1)^2 + (2 - .5)^2}$$

$$I_t = \sqrt{(1)^2 + (1.5)^2}$$

$$I_t = 1.8$$

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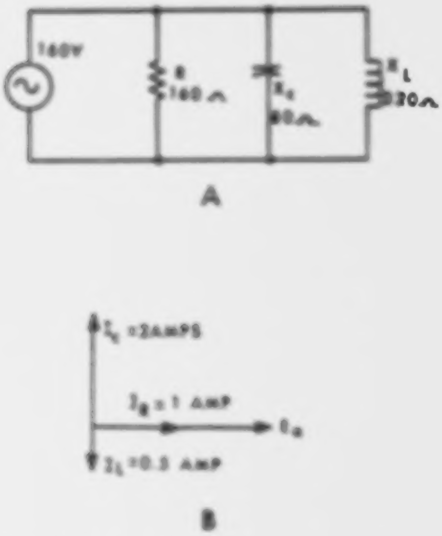

Figure 5-13. Parallel RCL circuit and current vector.

$$\text{Tan } \theta = \frac{I_C - I_L}{I_R} = \frac{(2 - .5)}{1} = \frac{1.5}{1}$$

$$\text{Tan } \theta = 1.5$$

$$\theta = 56.3^\circ$$

$$I_t = 1.8 \angle 56.3^\circ \text{ amps}$$

$$\text{and } Z = \frac{E_a}{I_t}$$

$$Z = \frac{160 \angle 0^\circ}{1.8 \angle 56.3^\circ}$$

$$Z = 88.9 \angle -56.3^\circ \text{ ohms}$$

Now let's turn to power and the power factor in parallel reactive circuits. You should remember from your study of basic components that purely reactive components do not dissipate power. Only the resistance in the circuit dissipates power, which is called true power. When reactive components and resistive components are connected in a circuit, the circuit appears to use much more power than it actually dissipates. This is called the apparent power of the circuit.

The apparent power (P_a) of series and parallel RCL circuits are found in the same way: $P_a = I_tE_a$. The formula for true power (P_t) is also the same in series and parallel circuits: $P_t = I_RE_R$. The power factor (PF) is also found in the same way in series and parallel circuits.

$$PF = \frac{P_t}{P_a}$$

Remember these important principles when solving simple parallel RCL circuits:

(1) Branch currents vary, but voltage is the same across all components.

(2) Vector diagrams use voltage as the reference, with currents added vectorally.

(3) Do not attempt to draw impedance diagrams for parallel circuits.

Exercises (460):

1. In a parallel RCL circuit, what voltage is applied across each branch circuit?

2. In a parallel RC circuit, what is the phase relationship of current to voltage in each branch?

3. In a parallel RC circuit, what is the value of total impedance in relation to the resistance of the individual component?

4. What is total current in a parallel RC circuit in relation to current for each branch?

5. Define true power as applied to parallel RCL circuits.

6. Define apparent power.

461. Identify the components and relationships of series resonant circuits, and cite the purpose of low- and high-pass filters.

Series Resonant Circuits. This is a continuation of your study of the series RCL circuit. As you know, inductive reactance and capacitive reactance have opposing impedance effects. If the frequency applied to a series RCL circuit causes the reactance values of C and L to be equal, these two impedances cancel each other. At this point, we arrive at the term "resonance." We first explain the conditions that exist when a series circuit is resonant, then analyze circuit operation by varying the frequency and impedance values above and below the resonant point to determine band width and selectivity. Resonant circuits are used in radar to control the frequency of operation of transmitters and receivers, in radio to permit the selection of stations broadcasting on different frequencies, and in telephone circuits to provide millions of people with voice communications. Resonant circuits are used in computers and instruments for operating systems, in navigation, and in other operations.

A series resonant circuit consists of inductors, capacitors, and resistors as shown in figure 5-14,A. Observe that X_L and X_c each have 5Ω resistors. If you drew an impedance vector diagram, you would find that X_L cancels X_c, leaving the 10Ω resistance as the only impedance. This is the minimum impedance possible in the RCL circuit. Total current equals applied voltage divided by this resistance:

$$I_t = \frac{E_a}{Z_T} = \frac{100V}{10\Omega} = 10 \text{ amps}$$

From this example, we can list the following important points concerning series resonance:

$X_L = X_c$

$Z = R = \text{minimum}$

$I = \frac{E}{R} = \text{maximum}$

$E_R = E_a$

$E_c = E_L$

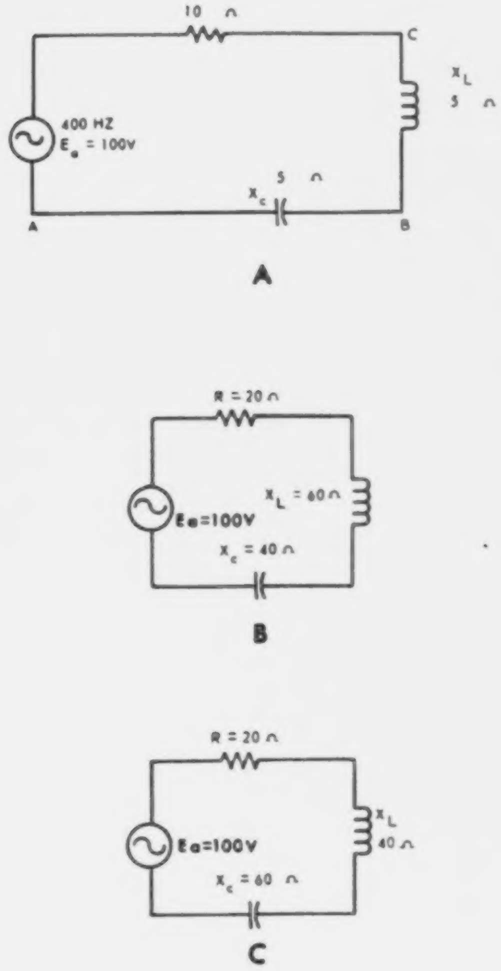

Figure 5-14. Series resonant circuits.

The frequency that causes the capacitive reactance and inductive reactance to be equal is the resonant frequency (f_r). When the resonant frequency is applied, the circuit is a resonant circuit.

If a variable frequency power source is applied, and the frequency is varied, there will be one frequency that causes resonance in an series RCL circuit.

In the circuit in figure 5-14,B, notice that the impedance of X_L is 60Ω and X_c is 40Ω. This circuit is not at resonance. If we decrease the applied frequency, X_L decreases and X_c increases. By decreasing the frequency, the circuit in figure 5-14,B, is above resonance because the frequency must be decreased to make the values of X_c and X_L equal.

In figure 5-14,C, notice that the impedance of X_c is 60Ω and X_L is 40Ω. This circuit is below resonance. To make a resonant circuit, the frequency must be increased to make $X_c = X_L$.

In summary, some facts regarding resonance frequencies are:

a. "Above resonance" refers to a circuit operating at a frequency higher than the resonant frequency.

b. "Below resonance" refers to a circuit operating at a frequency lower than the resonant frequency.

c. Above resonance there is more inductive reactance than capacitive reactance.

Current and voltage relationships. If you connect an ammeter, figure 5-14,A, at point A, B, or C, the current indication will be the same. This is a series circuit with one path of current. If you change the frequency from 400 to 800 Hz, X_c decreases and X_L increases. The change in frequency, however, has no effect on the 10Ω resistance or the in-phase current and voltage relationship across the resistor.

The voltage across the inductance always leads the current by 90°, and the capacitor voltage always lags the current by 90°. Of course, you must realize that in actual practice you can never completely remove resistance from capacitive and inductive circuits, so the voltage and current relationship will be something less than 90°. When you have a resonant circuit, the capacitive and inductive reactances cancel each other; and at this time, the circuit current, the resistor voltage, and the applied voltage are all in phase.

Since X_L and X_c both equal 5Ω, the reactance values cancel (Z = R), and I and E_a are in phase. The voltage drop across the 10Ω resistance equals the applied voltage (E_a).

Figure 5-14,B, shows a circuit that is above resonance. The circuit is inductive because X_L is 60Ω and X_c is 40Ω; E_c and E_L are out of phase; current and voltage across the resistor are in phase; and the series current is lagging the applied voltage by an angle less than 90°. The current lags the voltage in an inductive circuit, and an inductive circuit is above resonance.

Now, for below resonance, figure 5-14,C, shows X_c = 60 ohms and X_L = 40 ohms. The voltage is leading the current. The angle is 45° because the resistance and the resulting reactance are equal.

Filters. To study filters, let's combine the series resonant circuit with information from preceding lessons. A filter is a circuit consisting of a number of components grouped in such a way that they have a definite frequency characteristic. Filters are designed to pass a certain range of frequencies freely and to block another range of frequencies. They use the variations of inductive and capacitive reactance with frequency. The variation of impedance in series RCL circuits is used to pass or reject certain bands of frequencies.

The range over which passage occurs freely is called the bandpass (see fig. 5-15,A). The range over which poor passage occurs is the attenuation band. The frequency at which attenuation starts to increase rapidly is the cutoff frequency. Notice in the figure that we have a low and a high cutoff point. The cutoff points are also referred to as the half-power points. At these frequencies the circuit is dissipating only one half of the power it did when it was at resonance.

Before studying filters, let's review several relevant principles of the frequency response characteristics of the capacitor and inductor. Remember the basic formula for capacitive reactance and inductive reactance:

$$X_c = \frac{1}{2\pi fC}$$

and

$$X_L = 2\pi fL$$

If frequency increases, X_c decreases and X_L increases. If you increase frequency enough, the capacitor acts as a short, and the inductor acts as an open. Of course, the opposite is true; decreasing frequency causes X_c to increase and X_L to decrease. Here again, if there is a large enough change, X_c acts like an open and X_L like a short.

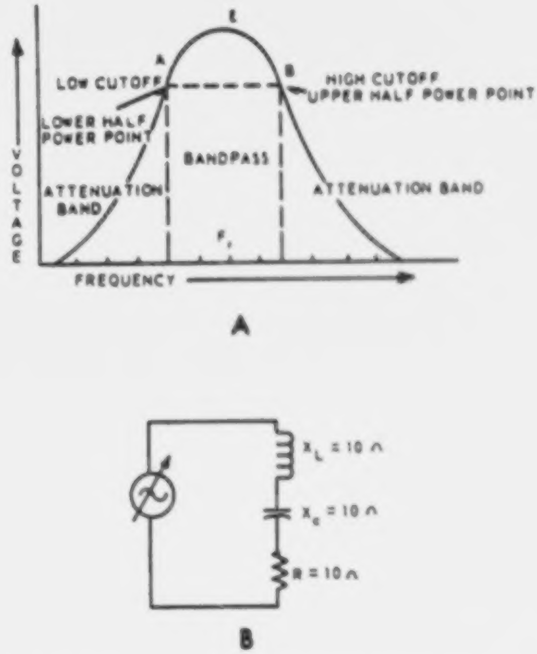

Figure 5-15. Series resonant circuit and frequency response curve.

Now let's see how we can use the series resonant circuit in figure 5-15,B, as a filter. Notice that X_L, X_c, and R are 10Ω each. You know that, at resonance, X_c and X_L are equal and opposite (180° out of phase); Z is minimum and current is maximum.

If you take an output across the resistor when the circuit is at resonance, you get the maximum possible voltage. As you detune that generator to either side of resonance, the output will decrease. This is shown by the frequency response curve in figure 5-15,B.

The frequency response curve is for a bandpass filter. The frequencies between the lower and upper half-power points pass to the next circuit. The other frequencies that fall below the lower half-power point, and the ones above the upper half-power point are filtered out; these two bands of frequencies fall in the attenuation bands. The half-power points are also the cutoff frequencies.

If the output is taken across both the inductor and capacitor, you have a type of "band reject" filter. Band reject filters are designed to reject a definite band of frequencies but pass all other frequencies.

Another filter of major importance to us is the low-pass filter. This filter does exactly what the name implies; it passes low frequencies and blocks high frequencies. Just opposite to the low-pass filter, the high-pass filter passes high frequencies and blocks low frequencies.

Exercises (461):

1. What components make up a series resonant circuit?

2. What are the I and Z in a series RCL at resonance?

3. As frequency increases, what happens to X_c and X_L in a series circuit?

4. In an RCL circuit, E_c = 10 volts and E_L = 20 volts. Does the circuit appear above or below resonance?

5. How is resonant frequency affected in a series RCL resonance circuit when either L or C is increased?

6. If frequency increases in an RCL circuit, what happens to X_c and X_L?

7. In an inductive circuit, does current lead or lag voltage?

8. How is the bandwidth of an RCL circuit determined?

9. Cite the purpose of low-pass and high-pass filters.

462. Name the components in a parallel resonant circuit, state the conditions of reactance at resonance, and cite the physical makeup and operation of a parallel tank circuit.

Parallel Resonant Circuits. In series RCL circuits, you learned that when the applied frequency makes the reactance values equal, the circuit is at resonance. The same principle holds true in parallel RCL circuits. Resonance occurs when the applied frequency makes $X_c = X_L$.

Figure 5-16,A, shows a typical parallel resonant circuit. First you know the 100 volts (E_a) is felt across each branch of the parallel RCL circuit. Further, the current in each branch is determined by the amount of reactance. Remember this: You cannot add these currents arithmetically, you must add them vectorially, because they are not in phase.

Current in the resistive branch of the parallel circuit is in phase with E_a; current in the capacitive branch is leading E_a; and current in the inductive branch is lagging E_a. We have redrawn the circuit in figure 5-16,A, to show that the inductor actually has resistance. In practical circuits, you will find that figure 5-16,B, is more representative of a parallel RCL circuit. Therefore, we will analyze the parallel RCL circuit through frequency change describing the path through which current will flow. (Since changing frequency has no effect on the amount of current that flows in the resistive branch, we will omit a discussion of this branch, for now.)

You learned previously that inductive and capacitive reactance varies with frequency. At a low frequency, X_L offers less reactance, and more current flows through the inductive branch (see fig. 5-16,B). Just the opposite is true for X_c; that is X_c offers more reactance and less current at low frequencies. Of course, everything reverses as frequencies increase.

In both of the extreme conditions, either high or low frequency, an ammeter installed (as shown in fig. 5-16,B) shows line current to be comparatively high. What about the frequency that causes the opposition offered by both branches to be equal? Will the canceling effect produce a high line current? The answer is "No." Since the reactances are equal and the same voltage is applied to both, the currents (I_c and I_L) will be equal and opposite as shown in figure 5-16,C. Because of the small resistance in the coil, the vector for current through the coil lags at an angle slightly less than 90°. When you add the vectors, the reactance values cancel, leaving a small amount of resistive current (I_t). The very small current indicates very high impedance. The total impedance equals the applied voltage divided by the total current:

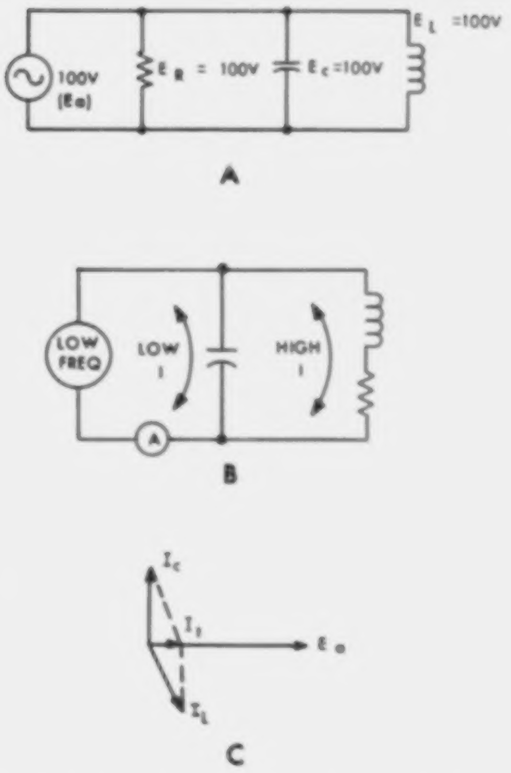

Figure 5-16. Current in a parallel circuit and current vector diagram.

$$Z_t = \frac{E_a}{I_t}$$

This parallel resonant circuit, called a tank circuit, presents a high opposition to the voltage force of the generator. Why does the tank set up an opposing force that is nearly equal to the generator force? Examine the action of an LC tank at resonance.

Place a charge across the capacitor as shown in figure 5-17,A. Moving the switch to the right removes the charging source and places the inductor in series with the capacitor. This furnishes a path for the excess electrons on the upper plate of the capacitor to flow through the inductor to the lower plate, thus neutralizing the capacitor charge (see fig. 5-25,B). As current flows through the coil, a magnetic field builds around the coil. The energy, which was first stored around by the electrostatic field of the capacitor, is now stored in the electromagnetic field of the inductor.

Figure 5-17,C, shows the capacitor discharged and a maximum magnetic field around the coil. Since the capacitor is now completely discharged, the magnetic field

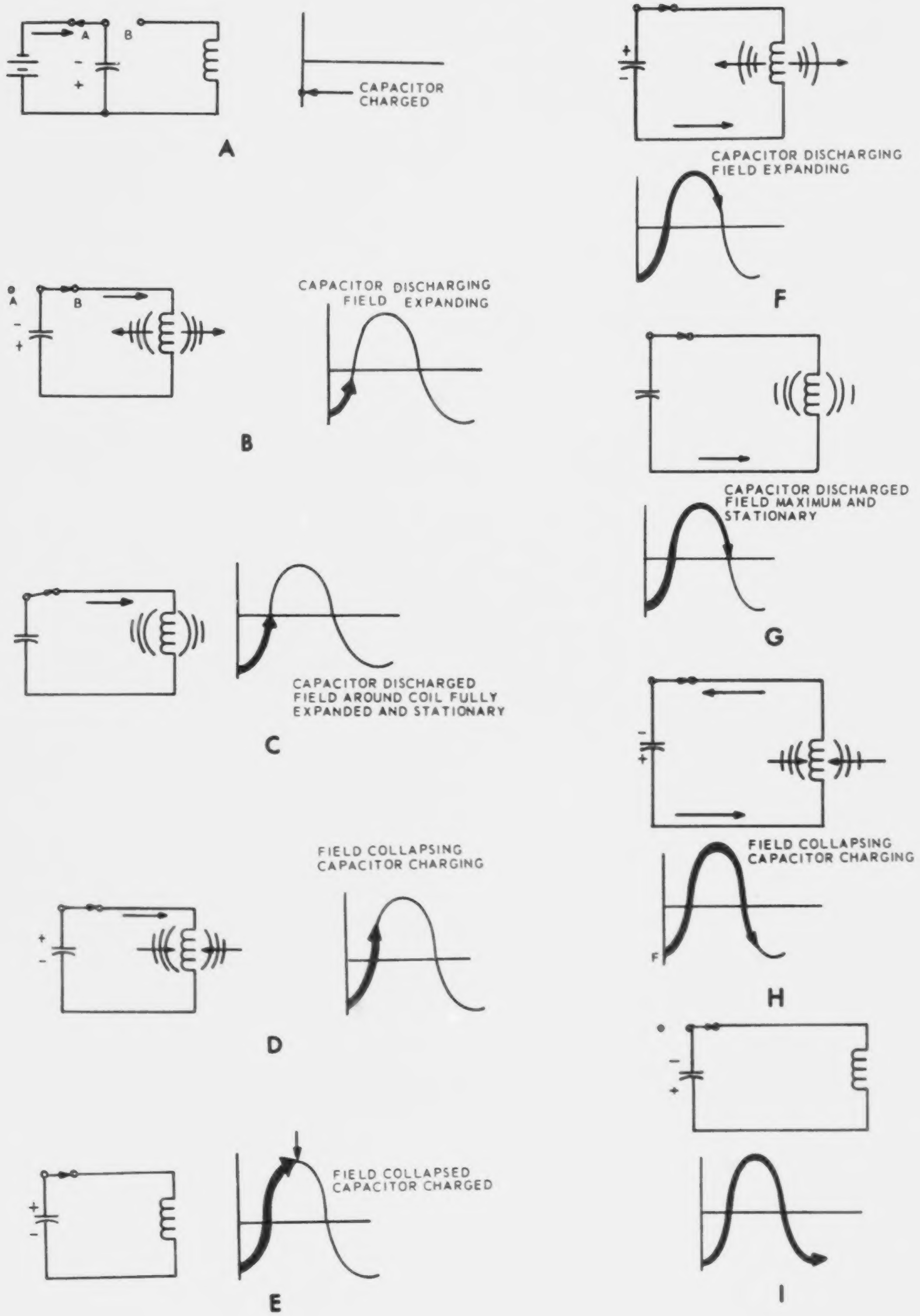
A
B
CAPACITOR CHARGED
A
A
B
CAPACITOR DISCHARGING FIELD EXPANDING
B
CAPACITOR DISCHARGED FIELD AROUND COIL FULLY EXPANDED AND STATIONARY
C
FIELD COLLAPSING CAPACITOR CHARGING
D
FIELD COLLAPSED CAPACITOR CHARGED
E
CAPACITOR DISCHARGING FIELD EXPANDING
F
CAPACITOR DISCHARGED FIELD MAXIMUM AND STATIONARY
G
FIELD COLLAPSING CAPACITOR CHARGING
F
H
I

Figure 5-17. Capacitor and inductor in a tank circuit.

starts to collapse (see fig. 5-17,D.) This induces a voltage in the coil, which causes the current to continue flowing, charging the capacitor again. When the inductor field has completely collapsed, the capacitor has become charged with the opposite polarity as shown in figure 5-17,E. The capacitor again starts to discharge (fig. 5-17,E). The inductor field increases (fig. 5-17,F) to maximum (fig. 5-17,G) as the capacitor is completely discharged. The inductor field collapses which continues current flow (fig. 5-17,H) to recharge the capacitor to its original polarity.

If the circuit is not opened, the discharging and charging actions continue. The number of times this set of events occurs per second is called the natural frequency or resonant frequency of the circuit.

In practical circuits, the heat loss of the resistance of the circuit causes each cycle to be smaller than the previous cycle. The result is a "dampened wave," as shown in figure 5-18,A. If it were possible to have a circuit with absolutely no resistance, this oscillation would continue indefinitely. The result would be a continuous sine wave (fig. 5-18,B) at the resonant frequency.

We said earlier that the opposing force of the tank could minimize line current. From previous lessons you learned that, in order for current to flow, a difference in potential must exist. Picture two generators or two batteries connected positive to positive with a lamp connected between them.

In the case of the battery circuit, it is easy to visualize that no current can flow through the lamp. No difference in potential exists. Likewise, if two generators are at exactly the same frequency and their outputs are identical, no differences in potential can exist, and no current can flow.

When an LC circuit is functioning at resonance, the same condition exists. At any instance along the EMF sine waves, the force of the generator is almost counteracted by the force of the tank. The amplitude of the tank force will be slightly less than that of the generator. For this reason, a minimum current flows in the line to replace the energy lost through heat, (I^2R).

You learned previously, that as frequency goes up above resonance, capacitive reactance goes down and inductive reactance goes up; similarly, as frequency goes down below resonance, X_c goes up and X_L goes down. With this in mind, you can see what will happen to current flow in a parallel RCL circuit. If the frequency is very low, X_L is low and X_c is high, so more current flows through the inductive branch. For example, if E_a = 100 VAC and X_L = 50 ohms, I_L = 2 amps. With X_c = 10K ohms, I_c = 0.1 amp and is relatively negligible when compared with the inductive current. Plotting these values on a vector diagram will show the line current (I_t) equal to 1.99 amps.

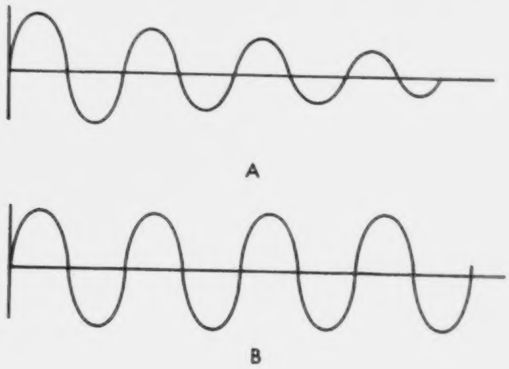

Figure 5-18. Dampened wave.

If the frequency is very high, the reactance values will reverse; X_c now offers 50 ohms of opposition, while X_L is 10K ohms. This results in high-line current, mostly through the capacitor.

With the resonant frequency applied, the tank circuit offers a very high impedance to the generator and, therefore, the line current decreases to a minimum. The series resonant circuit, as you recall, has minimum impedance and maximum line current.

Keep in mind that with the parallel resonant circuit, the capacitive current leads the applied voltage by 90°. These two currents are equal and opposite. When the capacitor is discharging, the discharge current flows through the inductor, storing energy in the electromagnetic field. When the magnetic field of the coil is collapsing, the resulting current flows in to the capacitor, storing energy in the electrostatic field.

The tank circuit has a small amount of internal resistance within the tank. This resistance dissipates energy as heat (I^2R) loss, so a small amount of line current is permitted to flow from the generator.

Since the line current is minimum at resonance, the tank impedance (Z tank) is maximum. This impedance across the tank should not be confused with the opposition offered to current flow within the tank.

Exercises (462):

1. What are the two main components of a parallel resonant circuit?

2. In a parallel resonant circuit, what condition, relative to reactance, must exist to have resonance?

3. As frequency decreases, does X_L offer more or less reactance?

4. What components make up a tank circuit?

5. How is line current affected when a tank circuit goes above or below resonance?

5-2. Coupling Circuits

"Coupling" is defined as the means by which signals are transferred from one circuit to another. Wires, resistors, coils, capacitors, or transformers may be used to couple. Coupling can be resistive, inductive, or capacitive. In this section, we will discuss direct-coupling, RC-coupling, LC-coupling, and transformer-coupling circuits.

463. State circuit input and output phase relationships and the correct coupling application.

Direct-Coupling. A direct-coupling circuit is shown in figure 5-19. The circuit shown uses a resistor for coupling, though a single conductor can be used. The single conductor coupling provides a direct path for signal currents. With this coupling, the signal at the output of the coupling circuit is an exact reproduction of the input to the coupling circuit. This exact reproduction, called high fidelity, is desirable. It also allows the DC voltage of the input circuit to be felt at the input to the second circuit.

The direct-coupling resistor shown in figure 5-19 is effective in series with parts of the input and output circuits. The DC voltage of the input feeds through the resistor to the output circuit. The loading effect of Z_L can cause a decrease in signal amplitude as the coupling resistor causes a voltage drop.

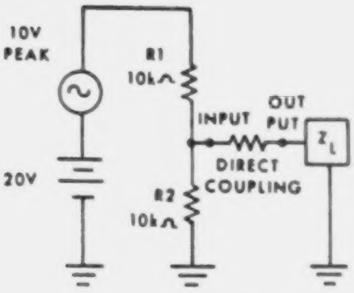
10V
PEAK
R1
10kΩ
INPUT
OUT
PUT
Z_L
DIRECT
COUPLING
20V
R2
10kΩ

Figure 5-19. Direct coupling.

Direct-coupling operates over a wide frequency range, beginning at 0 hertz. Remember that frequency does not affect resistance. Direct-coupling has no reactive components and is generally considered "resistive" with no phase shift.

RC-Coupling. Figure 5-20,A, shows a typical RC network connecting two circuits; this is an RC-coupling circuit. Observe that the capacitor (C1) blocks DC voltage from feeding to one circuit or the other. The signal applied to Z_L is taken from across the resistor. Notice that the coupling circuit output reference is zero. This is because the DC from the battery is blocked by C1.

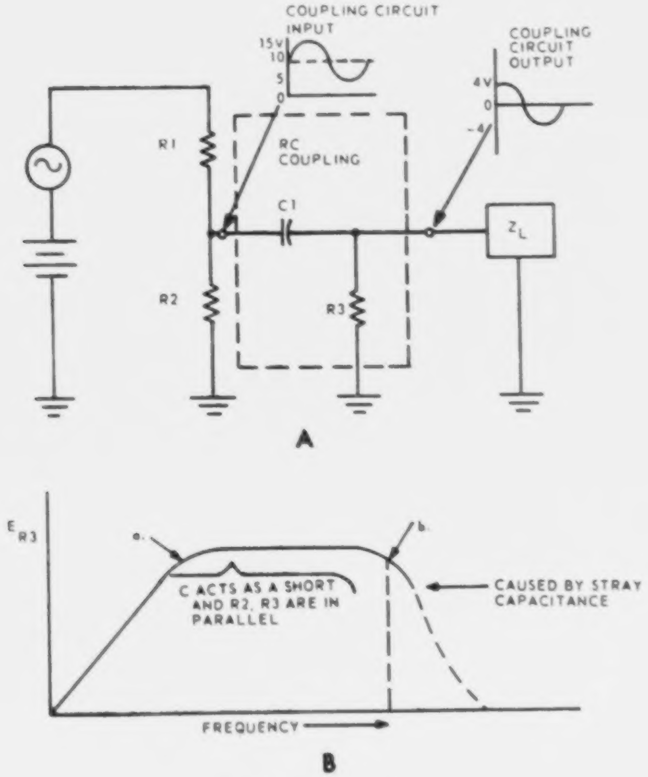
COUPLING CIRCUIT
INPUT
15V
10
5
0
COUPLING
CIRCUIT
OUTPUT
4V
0
-4
R1
RC
COUPLING
C1
Z_L
R2
R3
A
E_{R3}
a.
b.
C ACTS AS A SHORT
AND R2, R3 ARE IN
PARALLEL
CAUSED BY STRAY
CAPACITANCE
FREQUENCY
B

Figure 5-20. RC coupling.

An important consideration in RC-coupled circuits is the comparison between the relative magnitude and phase of the output voltage of the coupling circuit.

As we said in the preceding section, capacitor voltage lags capacitor current by 90°. This means that the signal voltage drop across R3 will lead the voltage across R2 by some angle between 0° and 90°. You can see this if you draw an equivalent series circuit, using the voltage across R2 and E_a with C1 and R3, the series components.

Now consider the effects of frequency on this type of circuit. The higher the frequency, the smaller the reactance of the capacitor, and the more resistive the circuit. When this happens, resistors R2 and R3 can be considered to be in parallel, and C1 can be considered as a short. R1, R2, and R3 act like a series parallel resistive combination. The frequency response curve of an RC-coupling circuit is shown in figure 5-20,B.

On the other hand, the lower the frequency, the greater the reactance of C1. This causes a smaller portion of the voltage across R2 to appear across R3 and a greater phase difference to exist between E_{R2} and E_{R3}, with E_{R3} leading. At 0 hertz, the capacitor completely blocks the signal, and the output signal drops to zero.

The voltage across R3 also drops off at the high frequencies. If we increase the frequency above point b in figure 5-20,B, a factor called stray capacitance attenuates the signal. Conductors form a capacitance, which is such a low opposition at high frequencies that the signal is greatly attenuated.

You can see, therefore, that there can be a large change in output voltage and phase when the frequency is varied. In practical RC-coupling circuits, the range of frequencies passed is determined by capacitance.

Between points a and b, the capacitor offers a minimum amount of impedance to the signal. The lower frequency limit of the RC-coupling circuit falls where $R = X_c$. The upper frequency limit falls at the the point where the output signal equals .707 of the input signal.

LC-Coupling. LC-coupling, like RC-coupling, is used in circuits with frequencies ranging from audio to RF. During our discussion of capacitors and inductors, we pointed out the relative impedance of these devices are various frequencies. Remember these characteristics in studying the action of the LC-coupling circuit.

Figure 5-21,A, shows an LC-coupling circuit connected between input and output circuits. At very low frequencies, X_c decreases and X_L increases. This causes the output to increase. At some frequency, C and L become series resonant ($X_c = X_L$). The output is then more than the input. A further increase in frequency causes the output to drop because, going away from resonance, current decreases; therefore, $I \times X_L$ decreases.

At some high frequency, the impedance of the capacitor becomes very low, so the capacitor acts as a short and the high reactance of the inductor is effectively in parallel with R2. The voltage output, then, will nearly equal the voltage across the resistor R2. The output is determined by the voltage divider made up of R1 and R2. In this circuit, the output voltage leads the input voltage.

Figure 5-21,B, is a typical response curve of an LC-coupling circuit. Study the notes on the figure. They should give you enough understanding to read a response curve. Both RC- and LC-coupling circuits are considered "capacitive" coupled circuits. Now turn to inductive coupling, where a signal moves from one circuit to another by transformer action.

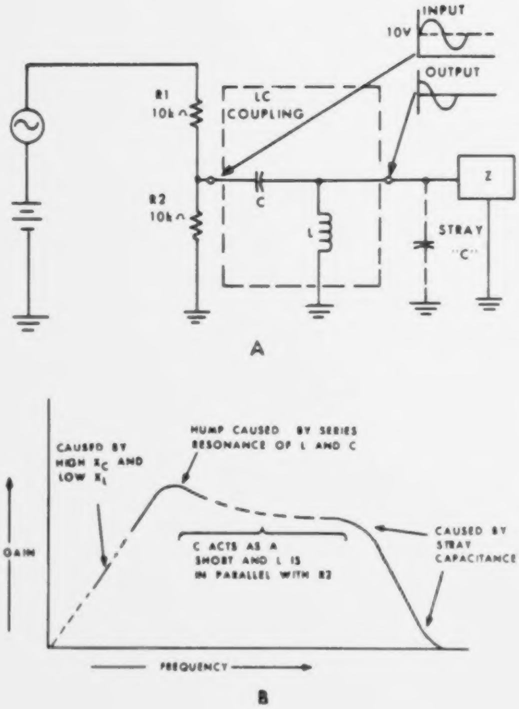
INPUT
10V
OUTPUT
R1
10k Ω
R2
10k Ω
LC
COUPLING
C
L
Z
STRAY
"C"
A
HUMP CAUSED BY SERIES RESONANCE OF L AND C
CAUSED BY HIGH X_C AND LOW X_L
GAIN
C ACTS AS A SHORT AND L IS IN PARALLEL WITH R2
CAUSED BY STRAY CAPACITANCE
FREQUENCY
B

Figure 5–21. LC coupling.

Transformer-Coupling. You studied three types of transformers, power, audio, and RF, in preceding portions of this volume. Of these, the audio and RF are used in coupling circuits. Coupling transformers consist of two or more coils that couple energy from one circuit to the other by mutual inductance. Depending on the frequency, a transformer uses a core of iron, a magnetic alloy, or air. The coil connected to the first stage is the primary winding, and the coil connected to the load is the secondary winding. The turns ration of the windings depends on whether the voltage induced in the secondary is to be larger or smaller than the voltage applied to the primary. The main area of concern here is why we use transformers in coupling circuits, rather than RC- or LC-coupling.

Transformer-coupling has certain advantages over other types of coupling circuits. You can get a voltage or current setup across the transformer. The two separate windings block DC voltage. The secondary winding provides the coupling circuit to the next stage. Transformer-coupling is also used to couple a high-impedance source to a low-impedance load, or vice versa, by choosing a suitable turns ratio.

Transformer-coupling has the disadvantages of greater cost, greater shielding requirements, and the possibility of poorer frequency response at the higher and lower frequencies.

Exercises (463):

1. In a direct-coupling circuit, what is the input and output phase relationship?

2. In an RC-coupling circuit, what is the input and output phase relationship?

3. Refer to figure 5-21 of your text. In the LC-coupled circuit, how is the value of the output signal affected by frequency change?

4. What type of coupling would you use to couple a high-impedance source to a low-impedance source, or vice versa?

Electron Tubes

A MOST IMPORTANT device that performs as an amplifier/rectifier is the electron tube. Electron tubes have been replaced in many applications by solid-state devices, but innumerable uses for tubes will exist for some time to come.

6-1. Electron Tube Operation

Electron tubes, such as the diode, triode, tetrode, and pentode, are major functional elements in the aircrew trainer. A vast amount of money and time has been spent on research since the discovery of what is known as the "Edison effect." Since that time, electron tubes have been improved by using better materials and better design, and even by putting two or more sets of tube elements in one envelope.

Regardless of these changes and additions to the functions that a tube can perform, the basic operation still depends on the Edison effect, in other words, electron emission.

464. Identify each type of electron emission used in electron tubes in terms of its definition, and state related structural characteristics of electron tubes.

Electron Emission. When sufficient heat is applied to a substance, a change in matter can be observed. Expansion and vaporization are two of the visible changes. When water boils, we can see the agitation and the vapor rising but we cannot see the molecules as they escape from the surface as water vapor. If the vapor is condensed, water is again formed.

Another action that cannot be seen when heat is applied to matter is the acceleration of electrons. Under certain conditions, an increase in electron velocity causes the electrons to be released from the substance and these electrons are ejected into space. This type of electron emission is called thermonic emission, because it is caused by heat.

Some of the electrons in the atoms of metals are very loosely bound to the nucleus. When the filament in an evacuated tube is connected to an electrical power source, electrons move along the filament and collide with other electrons. The collision between the electrons generates heat. Some of the moving electrons gain enough energy to overcome the attractive force of the parent body of metal and break away from the surface. However, if the heated body (emitter) is surrounded by atmospheric pressure, the gas molecules bounce a large number of the emitted electrons back into the emitter. When the emitter is enclosed in an evacuated envelope, there are no gas molecules to offer opposition, and a larger number of electrons remain in a "cloud" around the emitter. Also, in a vacuum, the emitter does not oxidize and destroy itself.

Continuing with our analogy of evaporation, just as water evaporation increases with an increase in temperature, electron emission also increases with an increase in temperature. Again, as in the case of the evaporation of liquid, the rate of emission is increased as the size of the emitting surface is increased. Thus, when sealed in an evacuated envelope or tube, the heated emitter of a cathode becomes a practical source of electrons for the operation of the electron tube.

Electrons must be given energy before they can be released from atoms. We have discussed one of the methods that is used to produce electron emission, namely, thermonic emission. Here are three other types of electron emission:

(1) Photoelectric emission—electrons are liberated by a beam of suitable light directed on certain metals.

(2) Secondary emission—more electrons, called secondary electrons, are emitted when ions or other electrons strike a surface with sufficient force. ("Ions" are described in this chapter under the heading "Gas Tubes.")

(3) Field emission—electrons are emitted as a result of an intense electric field at a surface.

Common substances suitable for thermal emitters in vacuum tubes are tungsten, thoriated tungsten, and oxide-coated materials. The oxide-coated materials emit at a much lower temperature than the tungsten or thoriated tungsten. In spite of the high temperature required to emit electrons from tungsten, it is widely used in high-power tubes because of its durability. Tungsten covered with thorium emits at a much lower temperature than pure tungsten.

The emitter (cathode) may be the filament (heater), or it may be an oxide-coated sleeve around the heater. The former is known as a directly-heated cathode, while the latter is an indirectly-heated cathode. Either AC or DC can be used on the heater. However, a directly-heated cathode powered with AC generates an objectionable AC variation in plate current.

The voltage and current required for heating the emitter to the proper temperature vary considerably in different tubes. Any tube manual gives you the filament voltage and current rating of a particular tube. Current ratings vary considerably for different tubes, even with the same voltage requirements.

Filaments can be connected in parallel when they have the same voltage rating. This is common practice in

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equipment using a transformer that steps down the line voltage to a suitable operating voltage.

When the filaments are connected in series directly to the line voltage source, the combined voltage ratings of all the tube filaments must equal the line voltage. Sometimes you find a resistor in series with the filaments. Always make certain that the filaments connected in series have equal current ratings. If any tube has a current rating lower than the others, a resistor is connected in parallel across the tube. This resistor carries additional current and makes the current rating of this part of the circuit equivalent to that of the other parts.

Exercises (464):

1. Match each term in column A to its definition in column B.

Column A	*Column B*
____ (1) Thermonic emission.	a. Electron emission caused when ions or other electrons strike a surface with sufficient force.
____ (2) Photoelectric emission.	b. Electron emission resulting from directing a beam of suitable light on certain metals.
____ (3) Secondary emission.	c. Electron emission resulting from an intense electric field at a surface.
____ (4) Field emission.	d. Electron emission caused by heat.

2. Name two reasons it is necessary for an emitter to be placed in a vacuum.

3. What two factors determine the rate of emitter emission?

4. In what type of cathode is the heater also the emitter?

5. What type cathode should be used for an AC heated tube?

6. What must the sum of the filament voltage ratings of tubes connected in series equal?

7. If a tube in series has a lower current rating than the other tubes, what circuit change is required?

465. Identify structural and operational characteristics of a diode tube.

Diode Tubes. The diode is the simplest form of vacuum tube. It contains two electrodes; a cathode and a plate. In the diode, a voltage is applied to the plate terminal and the cathode terminal. With a positive voltage applied to the plate and with the cathode heated, electrons flow from the cathode to the plate and return to the cathode through the external circuit. If a negative voltage is applied to the plate, the electrons surrounding the cathode are forced back toward the cathode and no plate current flows. Thus, in a diode, electrons flow from cathode to plate only when the plate is positive with respect to the cathode. When the plate is positive with respect to the cathode, the electrons (negative charges) that come from the cathode are attracted to the positive plate. This current flow is called plate current (symbol Ip). When alternating voltage is applied to the plate, the plate alternately assumes a positive and negative polarity. Plate current flows only while the plate is positive; since current flows through the tube in only one direction, it is said to be rectified and the output is pulsating direct current. Diode rectifiers are employed in power supplies to change AC to DC.

Diode characteristics. Diodes are designed to operate with a constant voltage and current supply to the filament. The amount of current flow from the cathode to the plate depends largely on the following factors: (1) the potential applied to the plate (meaning the potential of the plate with respect to the cathode) or the strength of the electrostatic field and (2) the size, temperature, and composition of the cathode. With the cathode at operating temperature, the plate circuit is somewhat proportional to the plate voltage. At some point, as the plate voltage is increased, the increase in plate current tends to fall off. A point is finally reached at which a further increase in plate voltage shows no appreciable increase in plate current. This is called the voltage saturation point of the diode.

Under normal operation, if the voltage from the cathode to the plate and the plate current are measured, the apparent tube resistance can be calculated by Ohm's law. This is the DC plate resistance and is defined as the ratio of plate voltage to plate current. The symbol for DC plate resistance is R_{dc}. The formula for DC plate resistance is:

$$R_{dc} = \frac{\text{plate voltage } (\Delta Ep)}{\text{plate voltage } (\Delta Ip)}$$

Another important tube concept is the AC plate resistance (r_{ac}). The AC plate resistance is the ratio of a change in plate voltage to a change in plate current. The formula for the AC plate resistance is:

$$r_{ac} = \frac{\text{change in plate voltage } (Ep)}{\text{change in plate current } (Ip)}$$

The ratios are not the same. For many diodes, the DC plate resistance is approximately twice the AC plate resistance. Because of the nonlinearity of the diode characteristic, neither of these resistances is constant for all conditions of operations.

Peak-inverse voltage rating. While it is true that the diode does not conduct when the plate is negative with respect to the cathode, if too great a difference in potential is applied across the tube (plate negative and cathode positive), the tube will arc over. The voltage that the tube can withstand (in a reverse direction) without breaking down is called the peak-inverse voltage rating. This varies for different diodes and must be considered in selecting a tube for certain purposes. A tube manual gives the peak-inverse voltage rating for the various diodes. For example, the peak-inverse voltage rating for a 6H6 tube is given as 420 volts. If the plate of a 6H6 tube is made more than 420 volts negative with respect to the cathode, an arc may occur from plate to cathode, destroying the tube.

Exercises (465):

1. Name the two electrodes of a diode tube.

2. What is the current that flows when the plate is positive with respect to the cathode?

3. What is the resultant waveform when a sinusoidal AC voltage is applied to a diode vacuumtube plate?

4. What happens to DC plate resistance when the voltage at the plate of a diode tube is doubled and the plate current remains constant?

466. Identify the components and operation of a triode tube.

Triode Tubes. A triode tube contains three elements; a grid, a cathode, and a plate. The grid is usually a mesh of fine wire that is placed between the cathode and the plate, as shown in figure 6-1,A. The wires of the grid are spaced in such a way that the physical movement of the electrons from the cathode to the plate are relatively unobstructed. If the grid is made more negative than the cathode, some of the electrons emitted by the cathode are repelled by the electrostatic charge on the grid and do not reach the plate—as a result, plate current is decreased. It follows that, as the grid voltage is made increasingly negative, few and few electrons reach the plate. Eventually, when the grid is made negative enough with respect to the cathode, no electrons reach the plate, and plate current is cut off completely. The point at which plate current ceases to flow is called cutoff, and the negative grid voltage required to stop the plate current is called the cutoff voltage.

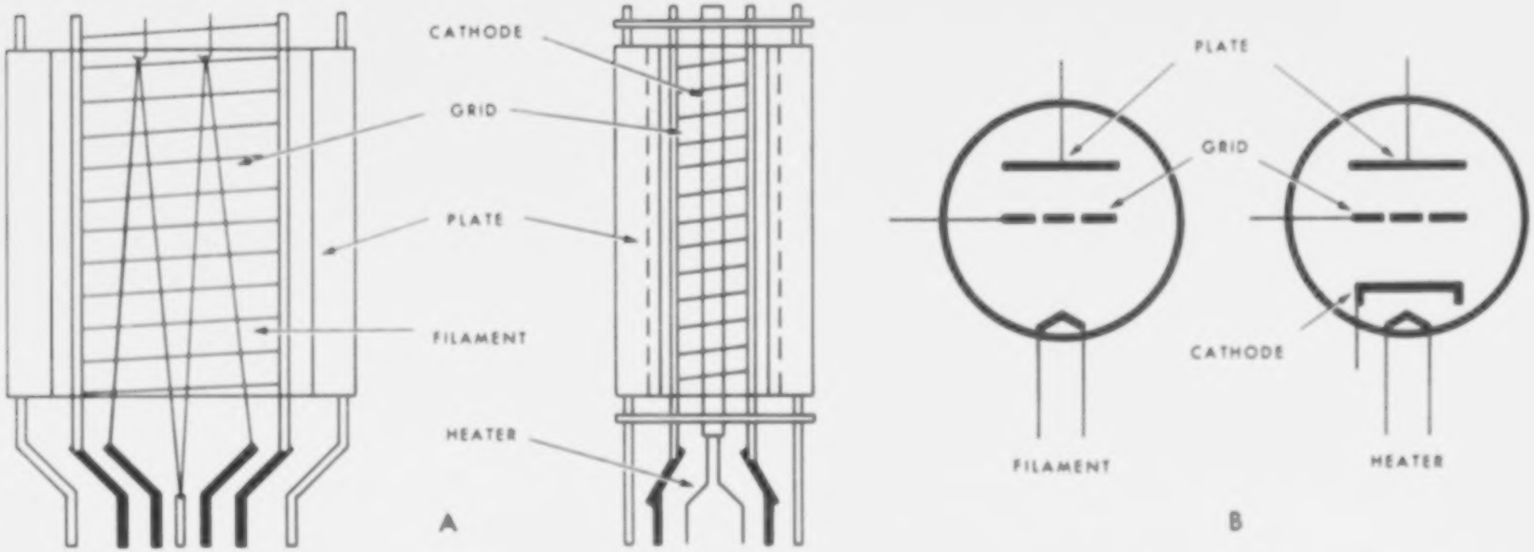
Going in the opposite direction from cutoff, plate current increases as you make the grid less negative. When the voltage on the grid becomes zero, it has no effect on the electrons passing from the cathode to the plate. If the grid is made positive with respect to the cathode, it aids in drawing electrons from the cathode and there is an increase in plate current. However, not all of these electrons go to the plate. The grid itself acts as an anode (plate), and grid current flows through the input circuit. If the grid is made positive enough, it attracts the majority of the electrons emitted by the cathode because *it is closer to the cathode than is the* plate. Because of this closer proximity to the cathode, a comparatively small change in the voltage on the grid in a triode has the same effect on plate-current flow as a much larger change in plate voltage. It is this feature that gives the triode ist chief property—amplification. The symbols for the directly and indirectly heat vacuum triodes are shown in figure 6-1,B.

Characteristics. A curve, or family of curves, as shown in figure 6-2, is obtained by applying a fixed plate voltage to a particular type of tube, and by varying the grid voltage within certain limits. The resulting plate current is then plotted on a graph. This is shown as an Ep–Ip curve. The several curves shown in figure 6-3 represent plots of plate current when the grid voltage is constant and plate potential is varied. This type of curve is called an Ep–Ip curve and is a static curve because it is obtained by using DC voltages under nonoperating conditions. Characteristic curves obtained under operating conditions are called dynamic curves. Dynamic curves are useful only when circuit elements are operated under the same conditions that existed when the curves were obtained. Static curves, although obtained under nonoperating conditions, give you considerable information about the tube under operating (dynamic) conditions. You can find the static curves for various tubes in some electron tube manuals.

The grid of a tube can be kept from going positive by adding a DC voltage equal to, or greater than, the AC voltage applied to the grid. If this added DC voltage is correctly connected, the resultant is a grid voltage varying through a range of negative values. With this type of voltage applied to the grid of a triode, grid current does not flow but the plate current still varies according to the AC output. Grid current can result in a distorted plate-current characteristic. The negative DC voltage applied to the grid, which makes the applied voltage negative, is called bias voltage. Normally, bias is applied directly and continuously to the grid and not to the applied voltage before it reaches the grid. There are three general methods of obtaining a grid-bias for vacuum tubes: fixed bias, cathode self-bias, and grid-leak bias, examples of which are shown in figure 6-4.

Fixed bias, figure 6-4,A, may be supplied by a battery (Ec) called a C battery. However, a battery often is inconvenient and is avoided if there is any other practical source of power. The voltage divider system is taken from a voltage divider located in the tube's external circuitry.

The cathode self-biase, figure 6-4,B, is one of the simplist methods of maintaining the grid of a tube negative with respect to the cathode. In this arrangement, a resistor Rk is placed between the cathode and ground, and the voltage drop developed by the plate current flowing through the resistor is applied to the grid. To keep this bias voltage applied to the grid constant and free from the effect of the AC variations in plate current, a capacitor (C), is connected in parallel with the cathode-bias resistor. The capacitor,


CATHODE
GRID
PLATE
FILAMENT
HEATER
A
PLATE
GRID
CATHODE
FILAMENT
HEATER
B

A. TRIODE STRUCTURE

B. TRIODE SYMBOLS

Figure 6–1. Typical triode structure.

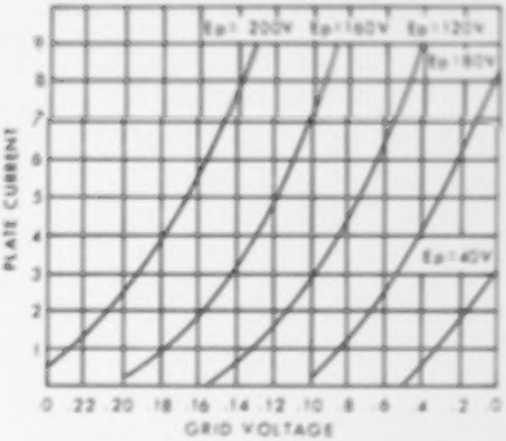


Figure 6-2. Eg-Ip curves for triodes.

which is connected across the cathode resistor, is called a cathode by-pass capacitor.

The grid-leak bias, figure 6-4,C, uses the flow of grid current during the first few cycles to develop a negative voltage for biasing the grid. When the grid-input signal is positive, grid current flows and the capacitor charges. When the input voltage becomes zero or negative, the capacitor starts to discharge through the closed path of the secondary of T and resistor, Rg. Since the value of Rg is quite high, the capacitor discharges slowly. After a few cycles of input signal, the capacitor develops a charge that makes the grid negative. Now the combination of capacitor charge and a negative input signal drives the grid toward a double negative potential. With a positive input signal and the capacitor charge, the grid is driven toward a zero potential. Under either of these conditions (after the first few cycles of input signal), the grid is negative and no appreciable grid current flows. Hence, the average grid potential is negative and the grid accepts electrons only when its voltage approaches zero.

Interelectrode capacitance. Recall from your resident school study, and from earlier discussions in this volume, that two conducting surfaces separated by an insulator (dielectric) form a capacitor. A capacitor is effectively formed by any two of the elements in a vacuum tube; by the plate and cathode, the grid and the cathode, or the grid and the plate. These capacitor effects (interelectrode capacitance) are shown in graphic form in figure 6-5.

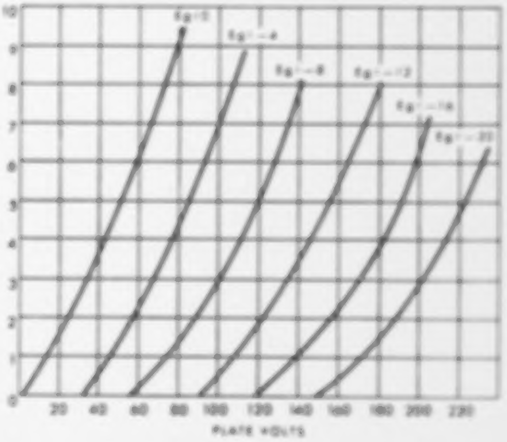


Figure 6-3. Eg-Ip curves.

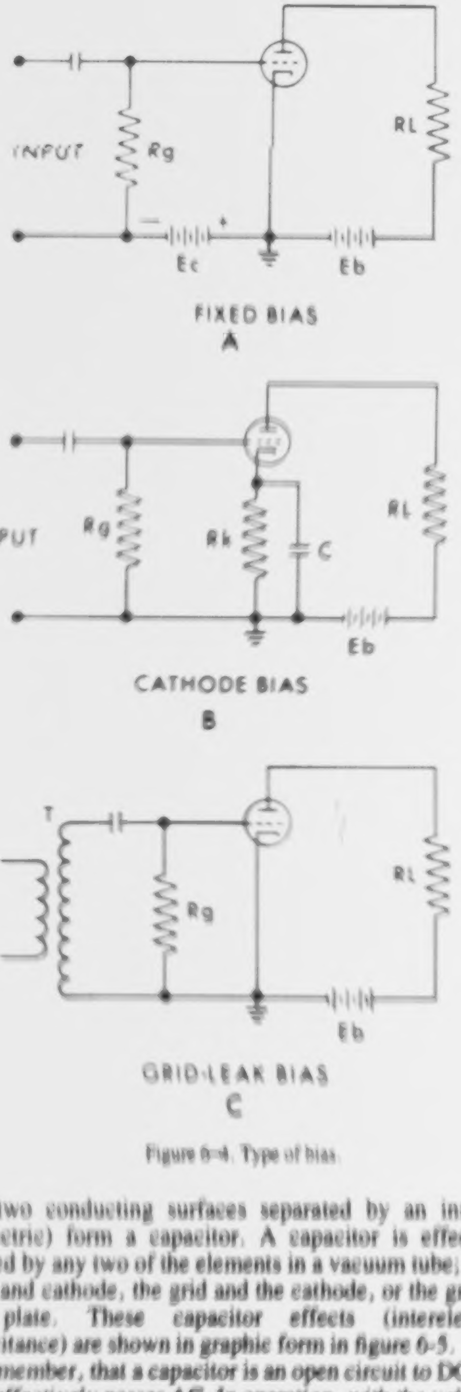


Figure 6-4. Type of bias.

Remember, that a capacitor is an open circuit to DC but it very effectively passes AC. In operation, with the voltage at the plate of a triode varying because of the changing voltage drop across the plate load, and AC signal is capacitively fed from the plate to the grid. This feedback influences the grid potential and can alter the input signal at the grid. In some instances, this feedback is desirable, but in amplifier applications it is undesirable.

The problem of plate-to-grid feedback is more pronounced at higher frequencies, because, as you already

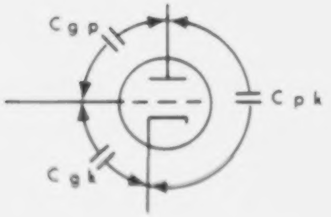


Figure 6-5. Interelectrode capacitance in a triode.

know, the amount of energy passed by a capacitor becomes greater as the frequency increases.

Triodes are especially susceptible to interelectrode capacitance feedback. However, the problem is reduced by the addition of another grid between the control grid and the plate.

Exercises (466):

1. *What three elements does a triode tube have?*

2. If the grid of the triode tube is made more negative than the cathode, is the plate current decreased or increased?

3. What is the chief property of the triode tube?

4. What do we call the characteristic curves obtained by using DC voltages under nonoperating conditions?

5. What are characteristic curves obtained under operating conditions are called?

6. What do we call a DC potential between grid and cathode (usually negative)?

7. What three interelectrode capacitances exist in a triode tube?

8. Which interelectrode capacitance of a triode tube introduces the most objectionable feedback in amplifier applications?

467. Specify the operational features of a tetrode tube.

Tetrode Tubes. If the electrostatic shield is inserted between the plate and the grid, interelectrode capacitance is greatly reduced. This shield is a mesh grid, a coarsely wound spiral of wire between the control grid and the plate that allows the electrons to pass through to the plate.

With this second grid added, the tube now has four elements and is called a tetrode. The structure and symbol of a tetrode are shown in figure 6-6. For maximum shielding, the screen grid should be at AC ground potential. This is accomplished by connecting a capacitor between the newly added screen grid and ground. To permit the flow of a reasonable amount of electron current, the screen must operate at a positive DC potential.

Usually the screen grid has, as shown in figure 6-7, a dropping resistor from B+ and a capacitor to ground. Some of the electrons strike the grid, thus causing a small amount of screen-grid current to flow. The voltage on the screen is then the applied voltage (B+) minus the voltage dropped across R1. Some of the electrons flowing from the cathode strike the screen grid and flow through both the screen grid and R1 on their way to B+. Thus, a voltage is developed across R1, and the postive DC voltage on the screen grid is equal to the applied voltage minus the amount dropped across R1. Assuming B+ to be constant, the size of R1 determines the positive DC operating potential applied to the screen grid. With C1 to ground, the potential on the screen grid is constant. With the screen grid at AC ground potential, it shields the control grid from any variations on plate potential. The cathode also is shielded from the plate by this same screen grid. As a consequence, electron

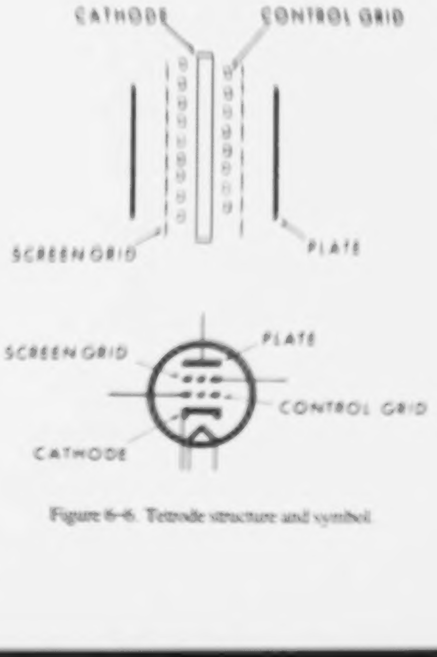


Figure 6-6. Tetrode structure and symbol.

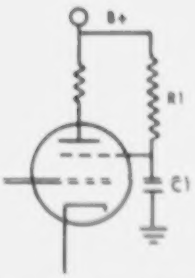


Figure 6-7. Dropping resistor and capacitor.

emission is affected very little by plate potential. It is determined altogether by the control grid and screen grid potentials.

The addition of the screen grid reduces the grid-to-plate capacitance and shields the grid from the effects of the varying plate potential. In turn, the screen grid is grounded through capacitor C1, which grounds out the capacitive effect produced upon it by the high-frequency signals of the control grid, thus maintaining the screen grid at AC ground potential. As a result, the tetrode is more useful for higher frequency work than the triode.

Secondary emission. In terms of the tube characteristics, the internal plate resistance, Rp, of a tetrode is much larger than that of a triode because a relatively large change in plate potential has less effect on plate current than in the case of a triode. For the same reason, the amplification factor, mu, is far greater than for a triode, while the mutual conductance, gm, remains about the same. Since the screen grid is very coarsely wound, the electrons pass through the turns with considerable speed and strike the plate. When these repidly moving electrons strike the plate, they may knock other electrons off the plate. This knocking off of electrons is called secondary emission.

The secondary electrons return to the plate only if the plate is more positive than the screen grid. If the screen grid is more positive than the plate, the secondary emission electrons are attracted to the screen grid and flow away as screen current. Since one electron striking the plate can knock off a number of electrons, the total plate current may become very small until the plate voltage increases to a value greater than the screen-grid voltage. The secondary emission results in a dip in the plate-characteristic curve at the lower plate voltages, where the screen-grid voltage is usually higher than the plate voltage. The dip is shown in figure 6-8. The screen grid is at a constant potential (point C in fig. 6-8). As a plate potential increases, the plate current increases. Below A on the graph there is little secondary emission since the electrons, because of their low velocity, do not dislodge others from the plate. From A to B, plate current drops with an increase in plate potential. The screen grid, because it is at a higher potential than the plate, attracts the secondary electrons. This is called the region of negative resistance; the dip is called the secodary emission dip or dynatron effect. At B, the plate current starts to rise as the plate collects more of the secondary electrons. At C, plate and screen voltages are equal, and more electrons are returned to the plate than are attracted to the screen. Beyond C, the field between the plate and screen becomes so strong that all secondary electrons are returned to the plate. Plate current is practically independent of plate voltage at the higher voltages. To eliminate distortion in a tetrode amplifier, the plate voltage must be high and only a small range of the curve may be used.

Exercises (467):

1. How does the screen grid in the tetrode tube affect the grid-to-plate capacitance and the amplification?

2. What determines electron emission in a tetrode tube?

3. The ___ or ___ region of a tetrode is that portion of the curve over which increasing plate voltage reduced plate current.

4. What is produced when electrons rapidly pass through the screen grid and strike the plate with enough force to knock other electrons off of the plate?

5. Distortion in a tetrode amplifier is eliminated by maintaining the plate voltage at a ___ level.

458. Identify the advantages of a pentrode tube over a tetrode tube from a list of vacuum-tube characteristics.

Pentode Tubes. In a pentode tube, a third grid is added to overcome the effects of secondary emission. The third grid, called the suppressor grid, is added between the screen

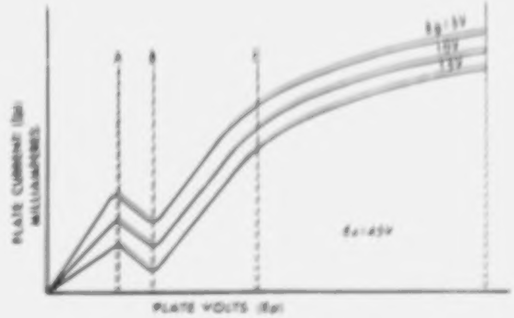


Figure 6-8. Characteristic curves of a tetrode.

and the plate and is usually connected to the cathode. Since the cathode is negative, the suppressor grid is negative, and, because of its position close to the plate it repels the secondary emission electrons back to the plate. The suppressor grid does not affect the flow of primary electrons to the plate, because their flow depends entirely upon the screen-grid and control-grid voltages.

The pentode has almost completely replaced the tetrode as an amplifier in most applications because it has the following advantages: (1) the rise of plate current at lower values of plate voltage is more rapid, (2) the negative resistance region is eliminated, (3) the straight portion of the characteristic curve has less slope, resulting in a greater change of plate voltage to obtain a noticeable change in plate current. These desirable qualities are shown by the pentode characteristic curve in figure 6-9.

Exercises (468):

1. *Indicate, by circling the letter at the left of each appropriate statement, which of the following statements are advantages of a pentode tube over a tetrode tube:*

   a. The rise of plate current at higher values of plate voltage is more rapid.

   b. This rise of plate current at lower values of plate voltage is more rapid.

   c. The positive resistance region is eliminated.

   d. The negative resistance region is eliminated.

   e. The straight portion of the characteristic curve has less slope.

   f. The straight portion of the characteristic curve has more slope.

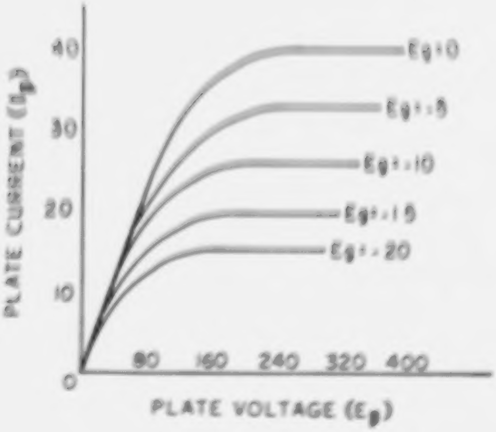


Figure 6-9. characteristic curves of a pentode.

469. Identify the uses and functions of various electron tubes, and state the purpose of a cathode follower circuit.

Special-Purpose Tubes. In addition to the types of tubes discussed so far, there are tubes of special design intended to give optimum performance in a particular application and to combine in one envelope functions normally requiring two or more tubes. Tubes of this type are called special-purpose tubes. The most frequently used special tubes are beam-power tubes, remote-cutoff tubes, multi-purpose tubes, and gas-filled tubes.

Beam-power tube. A special type of tetrode, shown in figure 6-10, which functions in the manner of a power pentode, is called a beam-power tube. In the beam-power tube, the screen grid is placed so that it is directly shadowed from the electron stream by the control grid. The electron stream is formed into narrow beams that pass between the windings of the screen grid without striking it. This means that the screen-grid current (which is wasted power) is very small, and the plate current is larger than would be expected.

Another outstanding feature is the presence of beam-forming plates. These are tied internally to the cathode and, because of their relatively negative potential, they repel the electrons to the extent of concentrating the electron beam before it strikes the plate.

The concentration of this beam of electrons is enough to form a considerable space charge in front of the plate. This space charge is sometimes called a virtual cathode and is

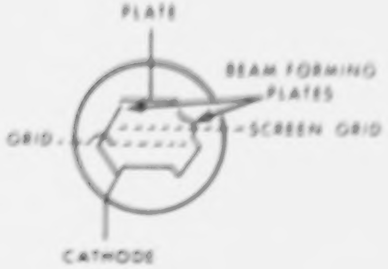


Figure 6-10. Beam-power tube elements.

sufficient to eliminate the effect of secondary emission in the tube, and so acts as a suppressor grid.

The plate current is much higher compared to an ordinary tetrode or pentode. Since power is proportional to current (I^2R), this is called a power-amplifier tube. A beam-power tube operating at the same voltage as a normal tetrode tube provides much more power output for a given input signal.

Remote-cutoff or variable-mu tube. A remote-cutoff, or variable-mu tube as it is sometimes called, is a tetrode or pentode voltage amplifier tube constructed in such a way that the plate current trails off gradually at highly negative control grid voltages rather than quickly at a well defined cutoff point, as in a tube using a sharp-cutoff grid. Figure 6-11 is a comparison of a sharp-cutoff tube and a variable-mu tube.

The coils of the control grid are spaced nonuniformly, as indicated in figure 6-12, giving a different amplification factor and cutoff voltage at different parts of the grid structure. This means that when the grid goes negative enough to cause the current flow through a part of the grid to cease (at the ends), it may still flow through some other portion (center) that requires more negative voltage to cut off the tube. For this reason, the plate-current flow tapers slowly, and requires a much more negative voltage than an ordinary tube for the plate current to reach zero. Remote-cutoff tubes are used in circuits employing automatic volume control and in circuits where the gain is controlled by varying the bias on one or more tubes.

Multipurpose tubes. A multipurpose tube contains two or more tube functions in one envelope. Frequently you find two diodes or two triodes located in the same envelope. Such tubes are known as duplex diodes or duplex triodes. Some of the other multipurpose tubes in common use are the duplex diode-triode and twin pentode. The advantage of multipurpose tubes is that they save space and make possible fewer and shorter leads within the electronic assembly and chassis.

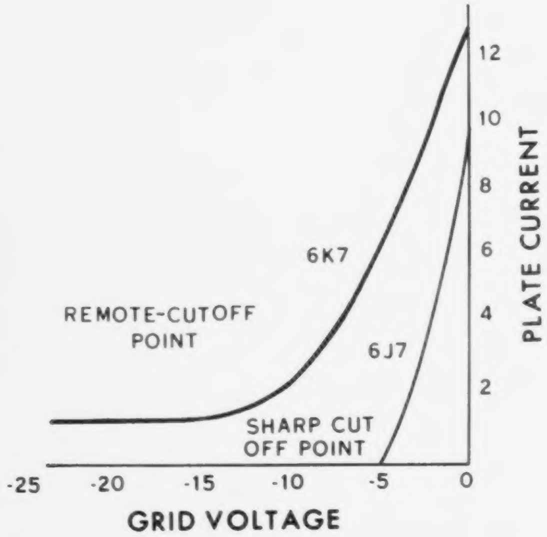


Figure 6–11. Comparison of sharp-cutoff and variable-mu tubes.

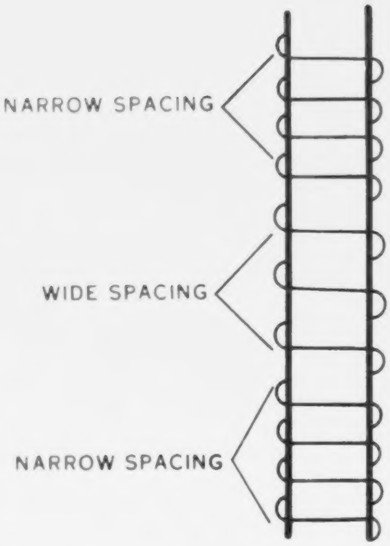


Figure 6–12. Spacing of grid windings in a variable-mu tube.

Gas tubes. Although the presence of gas in a high-vacuum tube is objectionable, some special-purpose tubes are gas-filled. Common gases used for this purpose are neon, argon, and mercury vapor. These gas tubes are sometimes spoken of as soft tubes, in contrast to the hard, or high-vacuum, tubes that we have preiously discussed. The schematic symbols of various types of gas-filled tubes are shown in figure 6-13. The small dot within the circle indicates that it is a gas-filled tube. The first two (A and B) have heaters; that is, the cathode is heated to produce thermionic emission. The VR (voltage regulator) tube (C) and the neon-glow tube (d) have no heaters and are termed "cold-cathode" tubes. In a cold cathode, sometimes called a glow-discharge tube, electrons from the inert gas atoms are released mainly through ionization by collision and by secondary emission at the cathode.

The operation and characteristics of gas tubes depend upon ionization. To ionize a neutral gas atom, such as argon and neon, we must change the electrical charge of the atom. When this happens, the gas atom is no longer neutral. The neon atom, for example, has 10 protons balanced by 10 electrons, thus making it neutral. It has neither a positive nor a negative charge. Now, if by some means an electron

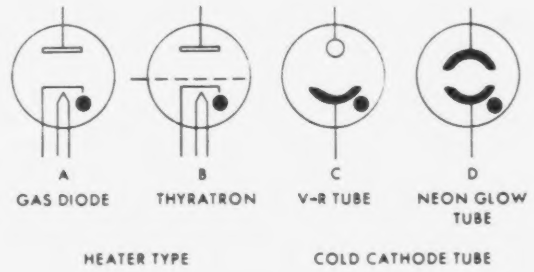


Figure 6–13. Symbols for types of tubes.

is forced to leave the atom, the atom becomes a positively charged ion, because there are 10 protons in the nucleus and only 9 electrons in its orbits. Likewise, if an electron was forced to enter a neutral neon atom, the atom would become a negatively charged ion, because there would be 10 protons in the nucleus and 11 electrons in its orbits. The process by which electrons are added to, or subtracted from, a neutral gas atom is called ionization.

In any gas-filled tube there are always some ions present, because the atoms have been ionized by cosmic rays, by radioactivity, or perhaps by light. As a potential is applied across the electrodes of the tube, the electrons drift toward the anode while the positive ions move toward the cathode. The kinetic energy (energy of motion) of either of these particles (electrons striking other atoms of gas, or positive ions striking the cathode) frees additional electrons. The electrons that result from these collisions constitute the tube current.

A certain minimum voltage difference is required between the plate and cathode to cause the electrons to move with sufficient velocity to produce ionization. This is the ionization potential, or firing potential. Likewise, the minimum value of plate voltage necessary to maintain ionization is called the extinguishing, or deionizing voltage.

After a gas-filled tube has fired, it behaves like a variable resistor when the applied voltage varies. The voltage at the plate of a gas-filled tube remains practically constant over a moderately wide range of plate current. This characteristic makes gas-filled tubes useful as voltage-regulator tubes, mercury-vapor rectifiers, and thyratrons:

a. Voltage-regulator tubes are designed to maintain a constant voltage drop from the anode (plate) to the cathode regardless of the voltage (within design limits) applied to it. Throughout our explanation of how a voltage-regulator tube operates, refer to the curve shown in figure 6-14 and the circuit shown in figure 6-15, which is the circuit used to produce the characteristic curve of the VR–75–30 tube. As the arm of the potentiometer, R1 in figure 6-15, is moved upward, the voltage applied to the circuit increases. A voltmeter across the tube reads the applied voltage, because the tube acts as an open circuit. Actually, a very small current flows (point 1 to 2 in fig. 6-14), but it is too small to be measured. When the applied voltage reaches about 100 volts (point 2), the tube fires and the voltage across the tube drops down to 75 volts. The firing potential of the tube is

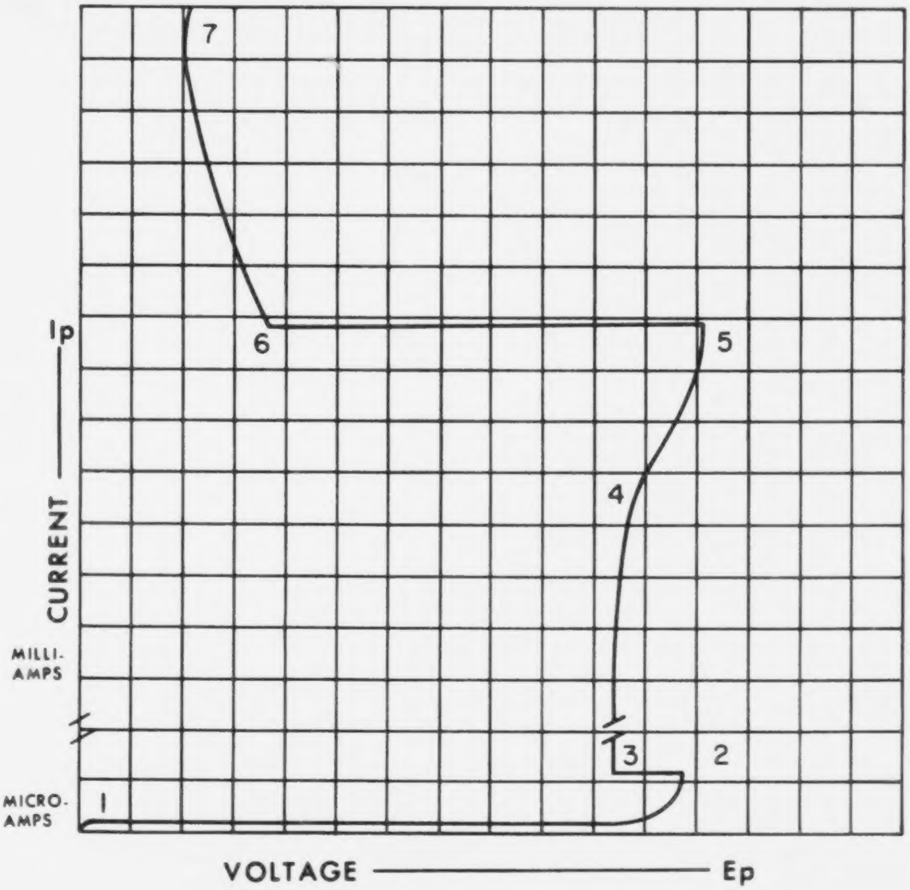


Figure 6–14. I-E curve for a cold-cathode gas tube.

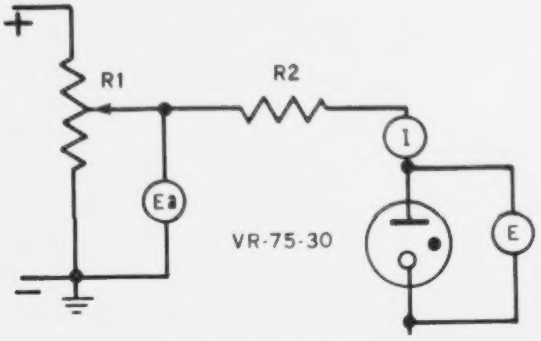


Figure 6–15. Circuit for obtaining the curve of a VR–75–30.

100 volts. As the applied voltage increases, the current flow increases, as is shown between points 3 and 4, but the voltage across the VR tube remains very nearly constant. The increased current flow indicates a decreased resistance in the circuit. Since R2 has a fixed value, the resistance offered by the gas tube must have decreased. But how? In order to answer this question, let's see what happens inside the VR tube.

When the applied voltage is increased, the plate potential also tends to increase. However, as the plate potential becomes more positive (increases), the electrons and positive ions traveling within the tube increase their speeds and ionize more of the neutral gas atoms. Because of the increased activity of the electrons and ions, more of the gas is ionized, resulting in a decrease in the resistance of the tube. This decrease allows more current to flow through the tube and the current-limiting resistor R2. Going back to the formula E = IR, apply the action just described to the formula and you will see why the plate voltage remains constant. In the formula, the resistance (R) of the tube decreases, then more current (I) flows through the tube. As a result, even though the values of I and R change, they change in such amounts that, when I is multiplied by R, E (the plate voltage) remains about the same. Since the resistance (degree of ionization) of the VR tube can change, the tube acts as a variable resistor. With an increase in applied voltage, more current flows through the VR tube and also through the current limiting resistor Rs. Since R2 is in series with the tube and has a fixed value, the increased current through R2 inceases the voltage drop across Rs. The increase in voltage drop across R2 is almost equal to the increase in applied voltage, and the plate voltage remains practically constant. Therefore, any increase (or decrease) in applied voltage is compensated for by the current limiting resistor R2 and the action of the VR tube.

The circuit shown in figure 6-15 is a gas-tube voltage regulator that provides a constant voltage (within limits) at the plate of the VR tube even though the applied voltage may change. The plate current can rise to 30 mA and still provide a regulated or constant output voltage. If the applied voltage is increased further so that the current rises about 30 mA (points 4 and 5 in fig. 6-14), the voltage across the tube begins to increase and can no longer be regulated, resulting in an increase in the output voltage. If the tube is operated very long at point 5, the cathode begins to heat and thermionic emission takes place at the cathode. Because of the thermionic emission, more gas is now ionized and the voltage at the plate drops back to point 6. If this condition is allowed to continue, the plate voltage drops farther back while the plate current soars up to point 7. About this time, the voltage-regulator tube destroys itself.

Assuming R2 to be in the circuit, if the applied voltage is now steadily decreased, the voltage across the tube remains constant until the plate current declines to about 5 ma at point 3 (fig. 6-14), and the tube tends to deionize. This is the extinction potential. The distance from 3 to 4 is the most linear portion of the curve, and it is in this region that the voltage-regulator tube operates. Only plate current changes over this portion of the curve. While the plate voltage (or output voltage) remains essentially constant.

Tubes designed to operate at specific voltages are the VR–75–30, VR–105–30, and the VR–150–30. The "VR" in the nomenclature means that it is a voltage-regulator tube. The first number (75, 105, or 150) stands for the voltage that is maintained across the tube, within 5 percent, if the current does not exceed 30 mA. The final number in the nomenclature (30) means the current. If the tube current drops below 5 mA, the regulation is very poor.

Mercury-vapor tubes are another type of gas-filled tube in wide use in the mercury-vapor tube. This tube contains a small amount of mercury, which vaporizes when the cathode is heated and ionizes when plate voltage is applied. The plate-to-cathode voltage drop is practically constant at 15 volts, regardless of the amount of plate current flow. Mercury-vapor diodes are widely used as rectifiers in power supplies where considerable current is drawn.

Thyratron tubes are a gas-filled triode or tetrode tube whose grid controls the ionization potential. The 884 tube is an example of a triode thyratron. The 884 thyratron characteristic graph is illustrated in figure 6-16. Notice that, as the grid becomes increasingly more negative, the tube requires more plate voltage to fire it or to cause the gas to ionize. Because of the grid's ability to control the firing point of the thyratron, this tube is used as an electronic switch. After the tube fires, however, the grid loses control of the tube. It cannot control the current flow through the tube because the positive ions cluster about the negative

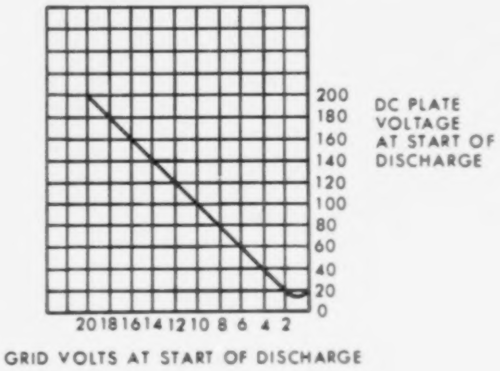


Figure 6–16. Characteristic curve of a thyratron.

grid neutralize its effect. In order for the grid to regain control over the thyratron, the tube must be dionized by removing the plate potential.

Cathode Follower. Figure 6-17 illustrates a cathode follower circuit. Note the absence of the plate load resistor that we have seen in previous tube circuits in this section. The load resistor is not in the plate, but in the cathode circuit. The tube current is determined by the signal voltage that exists between the cathode and the grid. Notice that the cathode reisitor (R_k) is common to both the input and output circuit.

As a positive voltage is applied to the grid, across the filter network of R_g and C_c, the tube current increases. This current increase causes the voltage drop across R_k to increase making the top of R_k more positive. As the signal voltage goes negative, tube current decreases, and the voltage drop across R_k decreases. The cathode voltage "follows" the input voltage.

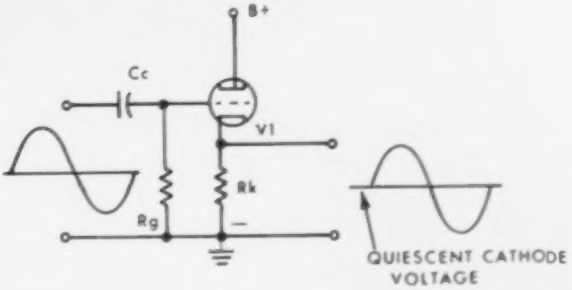


Figure 6-17. Cathode follower output.

The purpose of this type of tube circuit is to transfer a signal from a high-impedance network to a low-impedance network with maximum power transfer. The cathode follower tube circuit allows the matching of impedance networks with little or no power loss.

Exercises (469):

1. Place the letter or letters corresponding to the correct choice (column B) in front of the appropriate term (column A).

Column A

____ (1) Beam-power tube.
____ (2) Remote-cutoff or variable-mu tube.
____ (3) Multipurpose tube.
____ (4) Voltage-regulator tube.
____ (5) Mercury-vapor tube.
____ (6) Thyratron tube.

Column B

a. Use in circuits employing automatic volume control.
b. Contains two or more tube functions in one envelope.
c. Used as an electronic switch.
d. Used as rectifiers in power supplies where considerable current is drawn.
e. Used in place of a normal tetrode where more power output is desired for the same voltage values.
f. Used in circuits where the gain is controlled by varying the bias on one or more tubes.
g. Saves space and makes possible fewer and shorter leads within the circuit.
h. Maintains a constant voltage drop from anode (plate to cathode) regardless of the voltage applied to it.

2. What is the purpose of a cathode follower circuit?

CHAPTER 7

Semiconductor Devices

MOST OF THE PEOPLE employed in the field of electronics are aware of the growing popularity and importance of transistors. Yet few people not directly involved really understand what a transistor is or how it operates. The transistor is only one of the devices in the field of electronics that falls under the heading of solid state or semiconductor electronics. Our review of semiconductor devices covers such topics as atomic structure, charges, P–N junctions, housing, transistors and multivibrators.

7-1. Atomic Structure, Charges, Bias, and P–N Junction

In this section we will discuss atomic structure, energy bands, covalent bonding, crystals, positive and negative charges, current flow, P–N junctions, biasing, symbols, and ratings.

470. State different characteristics of the atomic structure of semiconductors.

Atomic Structure. The structure of an atom is best explained by an analysis of the simplest of all atoms, hydrogen. The hydrogen atom has one proton in its nucleus and one orbiting electron. The electron is held in orbit by two counteracting forces. One of these forces is centrifugal force. Thisforce tends to cause the electron to fly outward as it travels around its orbit. This is the same force that causes a car to roll off a highway as it rounds a curve at too high a speed. The other force acting on the electron is centripetal force. This force tends to pull the electron in toward the nucleus. Centripetal force exists because of the mutual attraction between the positive nucleus and the negative electron. At some precise radius, the two forces exactly balance each other. This balanced condition provides a stable path, or orbit, for the electron.

The electron in the hydrogen atom has two types of energy: *kinetic* (by virtue of its motion) and *potential* (due to its position). The total energy of the electron (kinetic plus potential) determines the radius of the electron orbit. As the radius of the orbit increases, the electron's energy increases.

Orbits, or shells, are identified by either a number or a letter. The K, or first shell, is the one closest to the nucleus and represents the lowest amount of energy. Going outward from the nucleus, an M shell represents more energy than an L shell; a P shell represents more energy than an O shell, etc.

These shells are also called permissible energy levels. As the name implies, these are energy levels where electrons can establish orbits. The permissible energy levels are separated by areas called forbidden energy levels. The quantum physics theory states that an electron cannot exist in the space between permissible energy levels. Therefore, every electron orbiting a nucleus must orbit in a permissible energy level. The permissible energy levels of an atom exist whether they are occupied by an electron or not. Even though hydrogen has only one electron in the K shell, the other shells still exist. The application of external energy (in the form of heat, light, etc.) to a hydrogen atom causes the electron to jump to one of the higher permissible energy levels. When the external energy is removed, the electron returns to the K shell. Electrons try to return to the lowest energy level possible.

The electrons in the outermost shell of an atom are the ones that enter into chemical or electrical combination with other atoms. These electrons are called valence electrons, and the outermost shell is called the valence shell.

The atomic number of an element represents the total number of electrons in the atom. The maximum number of electrons in any shell is determined by multiplying two times the shell number squared. States mathematically, this is $2 \times N^2$, where N equals the shell number.

Example: The maximum number of electrons permitted in the first (K) shell is $2 \times 1^2 = 2$ electrons. The maximum number of electrons permitted in the second (L) shell is $2 \times 2^2 = 8$ electrons. Note that while these are the maximum numbers, it is possible for a shell to contain less or even no electrons.

The atomic number of hydrogen is one, indicating that hydrogen has one orbital electron. The one electron of hydrogen is in the first or K shell, and the K shell is also the outermost shell. Therefore, the K shell of hydrogen is the valence shell.

The atomic number of germanium (which is a very common element in the manufacture of semiconductors) is 32. The 32 electrons if germanium are distributed in the following manner:

- K shell filled with two electrons (2×1^2).
- L shell filled with eight electrons (2×2^2).
- M shell filled with 18 electrons (2×3^2).

The four remaining electrons are in the N shell, which is the outermost shell. The four electrons in the outermost shell are valence electrons.

When the valence shell of an atom contains eight electrons, the atom is stable and does not attempt to gain or lose electrons (an exception is helium, which has two electrons in the K shell). Elements that have eight electrons in the valence shell include neon, argon, and krypton. Further, no atom contains more than eight electrons in the outermost shell.

Exercises (470):

1. Name and define the two forces that hold an electron in orbit.

2. What two types of energy does an electron contain?

3. What is a permissible energy level?

4. How are permissible energy levels separated?

5. State the quantum theory as it pertains to electrons and permissible energy levels.

6. Define valence electron.

471. Identify and define the parts of a valence electron.

Energy Bands. When atoms are brought close together, the individual energy levels of the atoms interact. If two silicon atoms (atomic number 14) were separated by a distance great enough to prevent the shells from overlapping, their energy levels would be identical. When the atoms are moved closer together so that their valence shalls overlap, the valence shells of the two atoms act as a single valence band. Only the outer shell has been affected; the inner shells retain the individual energy levels of the separate atoms. As more and more atoms are brought together to form a piece of silicon, the valence shell energy levels continue to interact until they form a solid permissible energy level. This is called the valence band.

Remember that energy levels exist whether they are occupied by electrons or not. These unoccupied energy levels also change when they are brought together with other atoms. Even though the N shells of the silicon atoms are unoccupied, they interact when brought together, forming another band of permissible energy level. This is called the conduction band. The conduction band and the valence band are separated by a forbidden level, called the forbidden band.

The electrons in the valence band are under the influence of the nucleus. The application of external energy can elevate a valence band electron to the conduction band. The applied energy must be sufficient to move the electron all the way across the forbidden band. The valence electrons never go halfway and stop. When an electron reaches the conduction band, it is considered to be free from the influence of the nucleus and is now able to move about. It is now a freelectron.

Substances with a large number of free electrons are called conductors. Copper wire is a good conductor, because it has many free electrons. The greater the number of free electrons, the better the conductor. In contrast to good conductors, some substances, such as rubber, glass, and dry wood, have very few free electrons and are poor conductors or insulators. Actually, there is no sharp dividing line between conductors and insulators, since free electrons exist to some extent in all matter. Substances falling between conductors and insulators are called semiconductors, and they are of prime importance in the study of solid state devices.

Energy is needed to elevate a valence electron into the conduction band. The amount of energy needed to elevate the electron determines whether the element is a conductor, an insulator, or a semiconductor. The energy level of a conductor is the energy level of the valence band overlapping the energy level of the conduction band. There is no forbidden band. All of the valence band electrons are already in the conduction band, and only a very small amount of energy is needed to cause them to move about. On the other hand, the distance between an insulator's conduction band and its valence band is very wide. A wide forbidden band means that it takes a large amount of energy to free an electron. The width of the forbidden band of a semiconductor material is between the extremes of the conductor and the insulator. For instance, the forbidden band of germanium is about one-tenth that of a diamond crystal insulator. Therefore, the energy required to elevate an electron to the conduction band of a semiconductor material is less than that required for an insulator, but more than that required for a conductor.

Exercises (471):

1. Define a valence band.

2. Define a conduction band.

3. What is a free electron?

4. What do you call a substance that contains a large number of free electrons?

5. Define an insulator.

6. What substances fall between conductors and insulators?

472. Define the valence of an element and identify the terms "covalent bonding," and "hole flow" in a semiconductor.

Covalent Bonding. The valence of an element is a measure of its ability to combine with other elements. It depends on the number of valence electrons in the element. For example, hydrogen has a valence of one and combines readily with other atoms. The reason is that the outer shell of the hydrogen atom requires two electrons to be complete, or stable. Oxygen has a valence of two because the outer shell has only six orbiting electrons. It needs two more to make up a full outer shell of eight electrons. Two atoms of hydrogen combine with one atom of oxygen to form a molecule of water. The force that holds the atoms together is called a covalent bond. A covalent bond is formed when valence electrons are shared by atoms. When water is formed, the two hydrogen atoms share their valence electrons with the oxygen atom so as to complete the outer shell of oxygen (total of eight electrons). At the same time, oxygen share one electron with each hydrogen atom to complete hydrogen's outer shell (total of two electrons). All three atoms now appear to have a complete outer shell and the molecule is stable.

In a "crystal lattice" structure the atoms or molecules are arranged in definite repeating patterns, and the external surface is a symmetrical arrangement. Germanium and silicon are both crystals. Atoms of germanium align themselves when a piece of germanium crystal is formed. A germanium atom has four valence electrons. To become stable, it must have a total of eight electrons in its valence shell. To accomplish this, each germanium atom aligns itself equally between its neighbor atoms. This arrangement allows each atom to share its valence electrons with neighboring atoms. Each germanium atom appears to have eight electrons in its outer shell. The covalent bonding of the germanium atoms makes the crystal stable and is the force that holds it together.

A pure germanium crystal, formed by covalent bonding, shares one electron with each of its four neighbor atoms. Thus, the center atom "sees" its own four electrons plus one each from the four neighbors, or a total of eight.

As we mentioned before, a semiconductor has characteristics between those of a conductor and those of an insulator. The electrons in the outer shell of the atoms of a semiconductor can be set free when enough external energy is applied. When electrons are freed, the material acquires some of the properties of a conductor. The heat contained by a pure germanium of silicon crystal at room temperature is sufficient to cause some of the valence electrons to break their covalent bonds and to be elevated to the conduction band. Every electron elevated to the conduction band leaves a vacancy in the valence band structure. This vacancy is termed a "hole" and acts like a mobile positive charge, equal and opposite to the electron's negative charge. The breaking of a covalent bond, producing a free electron and a hole, is called the generation of an electron-hole pair.

If a pure crystal of germanium or silicon, with broken covalent bonds, is subjected to a voltage, two kinds of current flow. The free electrons move through the crystal in the conduction band from the negative terminal to the positive terminal, constituting ordinary electron flow. The second current is hole flow in the valence band. Hole motion depends on the movement or shifting of valence electrons from one covalent bond to another. As a valence electron from a neighbor atom moves in to fill a hole, the hole reappears in the neighbor atom. Thus, holes seem to move in a direction opposite to that of electron flow, flowing from the positive terminal to the negative terminal in the valence band. It is important to remember that holes move only in the valence band. Therefore, current flow in a semiconductor is either electron flow or hole flow.

Exercises (472):

1. What is the valence of an element?

2. What is a covalent bond?

3. When does a crystal lattice structure exist?

4. What do you call the breaking of a covalent bond that produces a free electron and a hole?

5. Holes flow from ____ to ____ in a semiconductor.

472. Define an extrinsic crystal and identify the material and process for adding impurities to make semiconductors.

Crystal with Impurities. In the pure form, intrinsic germanium and silicon crystals are of no use as semiconductor devices. However, when certain impurities are added, the crystal can be made to conduct a useful current. To do this, the quality and quantity of the impurity must be carefully controlled. The added impurities create either an excess of electrons or an excess of holes, depending on the type of impurity added. With the impurity added, the crystal is called extrinsic. The impurities must align themselves in the crystal structure in the same way as the original crystal.

When arsenic is added to germanium, the arsenic atom forms a covalent bond with the germanium atoms. The arsenic atom has five valence electrons in its outer shell (pentavalent) but uses only four of them to form a covalent bond with the germanium atoms. This leaves one electron relatively free in the crystal structure. This extra electron can go into the conduction band and becomes a free electron. Because this impurity gives up or donates one electron to the crystal, it is called a *donor impurity*. Donor impurities are added to a crystal to increase the number of free electrons without increasing the number of holes. (This "adjusting" of electrons and holes is called doping.) The resulting material conducts by electron movement and is called a negative-carrier or N-type semiconductor. Other pentavalent impurities that are used as dopants are phosphorous, antimony, and bismuth. The amount of the impurity added is very small; it is on the order of one atom of impurity to 10 million atoms of germanium. The more impurities added, the more free electrons in the crystal.

A trivalent impurity element can be added to pure germanium to dope the material. As its name implies, this impurity has only three valence electrons. Thus, in one covalent bond there is only one electron instead of two. This arrangement leaves a vacancy in the covalent bond. The indium atom has one electron less than it needs to form a covalent bond with the four neighboring atoms. Therefore, a hole is created in the valence band. Because these impurities accept one electron from the crystal, they are called *acceptor impurities*. Acceptor impurities are added to a crystal to increase the number of holes without increasing the number of free electrons. The resulting material conducts by hole movement and is called a positive-carrier or P-type semiconductor. Other trivalent impurities that are used as dopants are gallium and boron. These acceptor atoms are neutral (the number of electrons in orbit equals the number of protons in the nucleus) when inserted into the crystal. When external energy releases an electron favorably close to the impurity atom, the acceptor captures or accepts the electron. This capture occurs as a result of the natural tendency of atoms to form complete covalent bonds. The acceptor atom thus stores an electron from the valence band structure of the crystal. The instant that a germanium valence electron leaves the bonding structure for storage, a hole is created in the valence band. Thus, a hole is actually a positive mobile charge and exists in the valence band.

Exercises (473):

1. What is an extrinsic crystal?

2. Name the process of adding an impurity with free electrons to a crystal.

3. Name the material that conducts by electron movement.

4. What type of impurity accepts one electron from a crystal?

5. What do you call a material with an excess of holes?

474. Identify positive and negative ions, the material they affect, and the majority carriers in N- and P-type material.

Changes in N- and P-Type Materials. When a donor impurity, such as arsenic, is added to germanium, the fifth electron in the outer ring of the arsenic atom does not become a part of a covalent bond. When acted on by some force, this extra electron moves away from the arsenic atom and begins a wandering movement in the crystal. As soon as the electron leaves, the arsenic atom becomes a positive ion (a positive ion is an atom that has lost an electron). Although there is a region of positive charge around the arsenic atom after the electron has moved away and a region of negative charge around the freed extra electron, the total charge of the crystal is zero. There are exactly the same number of electrons as there are positive charges (ions). However, in some regions in the crystal there are negative charges, and in other regions there are positive charges.

In P-type material, a similar situation exists. Suppose germanium is doped with indium. Indium has only three electrons in its valence shell. With only three valence electrons, there is a vacancy (a hole) in one of the covalent bonds. If an electron moves in to fill this vacancy, one more electron in the indium atom is needed to neutralize the positive charge (protons) of the nucleus. Thus, the indium atom has become a negative ion (an atom that has one electron too many). Similarly, when the germanium atom gives up an electron to fill the vacancy in the indium atom, the germanium atom will be short an electron, and there will be a region of positive charge around this germanium atom (hole). Even though the germanium atom gives up an electron and the indium atom gains an electron so that both become charged, the net charge on the P-type crystal is still zero. One atom is short an electron and another atom has one electron too many, but the crystal itself does not require any charge.

These ionized atoms produced in both N- and P-type materials are not concentrated in any one part of the crystal. If any region in the crystal were to have a very large number of positively charged atoms, these atoms would attract free electrons from other parts of the crystal to neutralize part of the charged atoms. These charges, then, would spread uniformly throughout the crystal. Similarly, if a large number of atoms within a small region had an excess of electrons, these electrons would repel each other and spread throughout the crystal.

Both holes and electrons are current carriers. The holes are positive carriers and the electrons are negative carriers. The one present in the greatest quantity is called the majority carrier; the other is called the minority carrier. In N-type material, electrons are the majority carriers and holds are the minority carriers. In P-type material, the holes are the majority carriers and electrons are the minority carriers.

Exercises (474):

1. What is a positive ion? In what type of material does this occur?

2. What is a negative ion? In what type of material does this occur?

3. Name the majority carriers in N-type material.

4. Name the majority carriers in P-type material.

475. State the direction of current flow in N- and P-type material, and explain negative temperature coefficient.

Current Flow in N- and P-type Materials. Conduction in the N-type semiconductor is similar to conduction in a copper conductor. That is, the application of voltage across the material causes the electrons in the conduction band to move through the crystal.

There are differences between an N-type semiconductor and a copper conductor with reference to temperature changes. For example, the semiconductor;s resistance decreases with a temperature increase because more carriers are made available at higher temperatures. Increasing the temperature generates more electron-hole pairs. This elevates more electrons to the conduction band and, thus, causes increased conductivity (decreased resistance). In the copper conductor, increasing the temperature increases the vibration of the structure and thus impedes current flow (increases the resistance). Semiconductors, therefore, have a negative temperature coefficient of resistance. As its temperature increases, the resistance of the semiconductor decreases.

Conductance in P-type material is by positive carriers (holes). In order for the hole to move, an electron in a nearby atom must move to the original position of the hole. Thus, the hole moves from the positive terminal to the negative terminal of the P-type material. Electrons from the external circuit enter the negative terminal and cancel holes in the vicinity of the terminal. At the positive terminal, electrons are removed from the covalent bonds, thus creating new holes. The new holes move from the positive to the negative terminal in the valence band. This process continues as the steady stream of holes (hole current) moves toward the negative terminal.

In both N-type and P-type materials, current flow in the external circuit consists of electrons moving out of the negative terminal of the battery and into the positive terminal of the battery. Also, both N-type and P-type materials have a negative temperature coefficient of resistance.

Exercises (475):

1. Current flow in N-type material is from to ____

2. What does "negative temperature coefficient" mean?

3. Majority current flow in P-type material is from to ____ to ____.

476. Explain how a P–N junction is made and define some of its characteristics.

P–N Junction. A semiconductor diode is manufactured by a chemical process where donor impurities are added to one region of a crystal and acceptor impurities are added to the other section. This gives a single crystal with an N section and a P section. The area between the N and P sections is called a junction. Metallic contacts are bonded to the two ends of the crystal. The result is a P–N junction or a junction diode ("diode" means two sections or elements). The P-type portion of the crystal contains the acceptor impurity. The other portion if N-type material containing the donor impurity. The end contacts are large surfaces that make a good connection with the crystal.

An isolated piece of N-type material is electrically neutral. For every free electron in the conduction band there is a positively ionized donor atom in the crystal structure. Thus, while there is an abundance of free negative charges, each charge is balanced by a fixed positive charge, and the overall charge of the N-type crystal is zero. The carriers are laced beside each ion to indicate the balancing of positive and negative charges. When the P-type and N-type materials are joined during the manufacturing process, a very interesting action takes place.

The electrons in the conduction band of the N-type material "see" the relatively empty conduction band of the P-type material and begin to diffuse (move or spread out) across the junction into the material. The free electrons lose energy, fall into the valence band and recombine with the holes. This recombination eliminates a free electron and a hole. When an electron has moved from the N material and diffused across the junction, a positive ion remains in the N material, which is no longer balanced by a negative charge. This same electron, upon recombination, eliminates a hole in the P material. This elimination of the hole produces a negative ion in the P material.

These ions are fixed in place in the crystal lattice structure and cannot move. Thus, they make up a layer of fixed charges on the two sides of the junction. On the N side of the junction there is a layer of positively charged ions; on the P side of the junction there is a layer of negatively charged ions. An electrostatic field is established across the junction between the oppositely charged ions. The diffusion of electrons across the junction continues until the magnitude of the electrostatic field is increased to a point where the electrons no longer have enough energy to overcome it. At this point, equilibrium is established and, for all practical purposes, the movement of carriers across the junction ceases. The action just described occurs almost instantly when the junction is formed. Only the carriers in the immediate vicinity of the junction are affected. The carriers throughout the remainder of the N and P material are relatively undisturbed and remain in a balanced condition. The free electrons in the N-type material move across the junction into the conduction band of the P-type material. When the electron moves and recombines with a hole, the junction barrier is formed. This barrier has both height and width. The physical distance from one side of the barrier to the other is referred to as the "barrier width." The width of the barrier, with no external potential applied, depends on the density of the mobile carriers in the crystal. The barrier height or "potential hill" is the difference of potential across the depletion region (intensity of the junction field). As the recombination of electrons and holes continues, the barrier becomes wider and taller. Equilibrium occurs when the barrier is large enough to prevent further recombination of electrons and holes. In other words, the barrier, or space charge, prevents total recombination.

A limitation imposed on the junction diode is the result of electron-hole pairs being formed at random when the crystal is subjected to heat, light, or electromagnetic radiation.

The electron-hole pairs that are generated produce minority carriers. There are minority carriers in both regions: holes in the N material and electrons in the P material. The direction of the junction field is such that minority carriers are readily accelerated and pass across the junction. The holes neutralize some of the negative ions on the P side of the junction. Similarly, free electrons produced by the P side of the junction pass across the junction and neutralize some positive ions on the N side of the junction. This movement of minority carriers is called intrinsic condition because the electrons and holes involved come from the generation of electron-hole pairs in the crystal lattice structure and not from impurity atoms.

When external heat is applied to a P–N junction diode, some of the electrons in the lattice structure break their covalent bonds and go to the conduction band. In the P-type material, the free electron is the minority current carrier. In the N-type material, the hole is the minority current carrier. It is relatively easy for the electron in the P-type material to "slide down" the barrier into the N-type material and for the hole in the N-type material to "slide up" the barrier into the P-type material. This intrinsic conduction is also called minority current.

Exercises (476):

1. Briefly explain how a P–N junction diode is constructed.

2. Define "potential hill."

3. What is a limitation or disadvantage of the junction diode?

4. Define "intrinsic conduction."

477. Define the term "forward bias," and briefly explain current flow in forward and reverse biased P–N junctions.

Bias. A battery connected across the P–N junction develops a bias across the junction. If the battery is connected so that its voltage opposes the barrier potential across the junction, it will reduce the height and width of the junction barrier and aid current flow through the junction. The junction is then biased in the forward direction (low resistance). If the battery is connected across the junction so that its voltage aids the barrier potential across the junction, it will increase the height and width of the junction barrier and oppose current flow through the junction. The junction is the biased in the reverse direction (high resistance).

Forward bias. In the forward bias connection, the positive terminal of the bias battery is connected to the P-type material and the negative terminal of the battery is connected to the N-type material.

The positive potential connected to the P-type material repels holes toward the junction, because germanium valence electrons are being attracted by the positive terminal of the battery. The holes moving toward the junction neutralize some of the negative ions at the edge of the junction barrier.

In the N-type material, the negative potential repels electrons toward the junction. These electrons neutralize some of the positive ions at the edge of the junction barrier. Since ions on both sides of the barrier are being neutralized, the barrier is decreasing in both width and height. Thus, the effect of the battery voltage in the forward bias direction is to reduce the barrier potential across the junction and to allow majority carriers to cross the junction.

In a forward biased P–N junction, an electron leaves the negative terminal of the battery and moves to the terminal of the N-type material. It enters the N-type material, where it is the majority carrier, and moves to the edge of the junction barrier. Because of forward bias, the barrier offers less opposition to the electrons and they pass through the depletion region into the P-type material. The electron loses energy in overcoming the opposition of the junction barrier and, upon entering the P-type material, combines with a hole. The hole was created when an electron was pulled out of the P-type material and drawn to the positive terminal of the battery. Thus, the hole moved toward the junction.

It is important to remember that in the forward biased condition, conduction is by majority current carriers (holes in the P-type material and electrons in the N-type material). Increasing the battery voltage increases the number of majority carriers arriving at the junction, and the current flow increases. If the battery voltage is increased until the barrier potential across the junction is completely neutralized, heavy current flows and the junction may be damaged from the resulting heat.

With a forward bias voltage across the P–N junction, the barrier height and width decreases. This represents a lower resistance and, therefore, more current flow.

Reverse bias. To reverse bias a junction diode, connect the negative battery terminal to the P-type material and the positive battery terminal to the N-type material. The negative potential attracts the holes away from the edge of the junction barrier on the P side while the positive potential attracts the electrons away from the edge of the barrier on the N side. This action increases the barrier height and width, because there are fewer holes on the P side of the junction to neutralize the negative ions and few electrons on the N side to neutralize the positive ions. The increase in barrier potential prevents current across the junction by majority carriers.

In a reverse biased P–N junction, the width of the junction barrier is increased. The concentration of the mobile carriers at the terminals has left many ions unneutralized at the edge of the barrier, therefore, the junction field will extend to include these ions.

With a reverse bias voltage across the P–N junction, the barrier height and width increase. This represents a higher resistance and, therefore, less current flow.

The current flow across the barrier is not zero, however, because of minority carriers crossing the junction. Holes forming in the N material are repelled toward the junction, and electrons being released in the P material are repelled (by the battery) toward the junction. In both cases, these are minority carriers. The junction field aids minority carriers only. Therefore, when the minority carriers reach the junction barrier, they are accelerated across the junction. This situation was described earlier as intrinsic conduction.

Thus, under reverse bias conditions there is a small current flow, due to minority carriers crossing the junction. This current flow is small at normal operating temperatures. However, as temperature increases, the minority current increases.

Exercises (477):

1. What is forward bias?

2. How is the battery connected for forward bias?

3. What kind of carriers are responsible for conduction when the junction is forward biased?

4. When a P–N junction diode is reverse biased, is there any current flow? If so, what carriers are responsible?

5. With reverse bias, as temperature increases, does minority current increase or decrease?

478. Identify the symbol used for P–N junctions, define the characteristics on which junctions are rated, and explain their behavior in a circuit.

P–N Junction Symbol and Ratings. The schematic symbol of a P–N junction is an arrow with a bar across the front. The bar represents the cathode and the arrow represents the anode. External current flow is against the arrow. This symbol is shown in figure 7-1.

P–N junction diodes are generally rated for maximum average forward current; peak forward current; maximum surge current; and peak reverse voltage (PRV).

Maximum average forward current is usually given at a specified ambient temperature (usually 25°C.), and refers to the maximum amount of average current that can be permitted to flow in the forward direction. Typical values of current for silicon diodes range from 150 mA to 250 amperes.

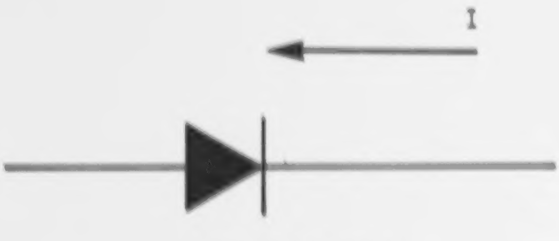


Figure 7-1. Diode symbol.

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Peak forward current is the maximum peak current that can be permitted to flow in the forward direction in the form of recurring pulses.

Maximum surge current is the maximum current permitted to flow in the forward direction in the form of nonrecurring pulses. Current should not equal this value for more than a single forward cycle of diode operation.

Peak reverse voltage is one of the most important ratings. PRV indicates that maximum reverse bias voltage that can be applied to a diode without causing structure breakdown.

All of these ratings are subject to change with temperature variations. If the operating temperature is above that stated for the ratings, all the ratings must be degraded by an appropriate amount.

A P–N junction diode is a nonlinear device, whereas a resistor is a linear device. You can see some very interesting differences by plotting the current-voltage relationships of each device and then comparing the results. The chart in figure 7-2 shows the result of plotting voltage against current for a 200-ohm resistor. Various points can be determined by the formula E = IR or I = E/R. Then you plot and connect these various points. The result is this: Since the resistance of the resistor does not change, the current-voltage relationship remains the same. The current-voltage relationship for a 200-ohm resistor is 1:200; you can verify this by selecting a point on the line and comparing the current in amperes to the voltage in volts.

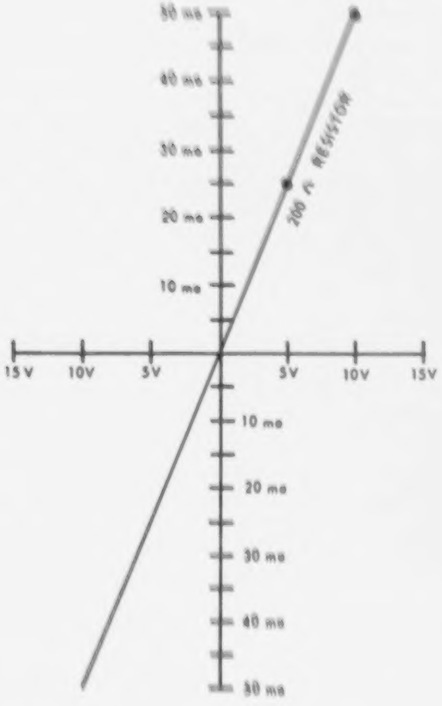

Figure 7-2. Current and voltage relations for a 200-ohm resistor.

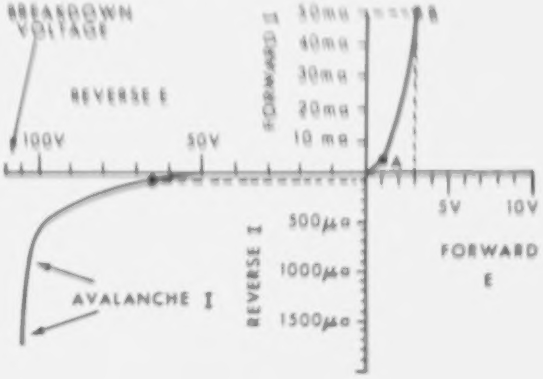

Figure 7-3. Current and voltage characteristics of germanium diode IN63 (25° C.).

The voltage-current characteristic curve of a P–N junction diode is shown in figure 7-3. The forward portion of the curve shows that the diode conducts easily when the potential across the junction is in the direction of forward bias (P side positive and N side negative). You can compute the resistance from the static curve by using the formula R = E/I. At point A in figure 7-3, the forward voltage is approximately 1 volt and the forward current is approximately 5 mA. This represents about 200 ohms of resistance (a current-voltage ratio of 1:200). At point B, the voltage is 3 volts and the current is 50 mA. This gives about 60 ohms of resistance for the diode (a current voltage ratio of 1:60).

The diode conducts poorly in the high resistance direction (reverse bias, P side negative, and N side positive). In this condition, the holes and electrons are drawn away from the junction, causing an increase in the barrier potential. At point C in figure 7-3, the voltage is about 80 volts and the current is about 100 microamps. The diode has about 800K ohms of resistance (a current-voltage ratio of 1:800,000). This indicates the nonlinear characteristics of a P–N diode.

If the reverse bias is increased beyond a critical value, the reverse current increases rapidly because of avalanche breakdown. The peak reverse voltage ranges from a low of approximately 40 volts to a high of 1000 volts for general applications, with special types extending to approximately 12,000 volts.

Avalanche current breakdown occurs when the applied voltage is large enough to break down the covalent bond structure (fig. 7-3). At this point, a sharp rise in reverse current occurs. The acceleration of the new holes and electrons continues until they have violent collisions, with the valence band electrons of the germanium crystal atoms releasing more and more carriers. Because of the heat generated, the diode is damaged beyond repair.

Many types of semiconductor diodes are available. They vary in size from hardly bigger than a pinhead, used in subminiature circuitry, to large 250-ampere diodes, used in high-power circuits.

Exercises (478):

1. What do the bar and arrow represent in a diode symbol?

2. Which way does the external current flow through a diode?

3. Name four things P–N junction diodes are generally rated for.

4. Define maximum average forward current.

5. Define peak forward current.

6. Define peak reverse voltage.

7. Define maximum surge current.

8. As compared to a resistor, a diode is a ____ device.

9. If reverse bias is increased beyond a critical value, what causes the reverse bias current to increase rapidly?

10. When does avalanche breakdown occur?

7-2. Transistors

The transistor is another electronic device that uses the flow of current carriers through a semiconductor. You have reviewed two-element semiconductor diodes, which permit more current flow in one direction than the other; they have the ability to rectify. The next semiconductor device that you will examine has three elements and can amplify.

479. Name the parts and classes of transistors and state how they are formed.

Parts of a Transistor. Semiconductor devices with three or more electrodes are called transistors. The term "transistor" was derived from the words "transfer" and resistor." There are many different types of transistors, but the theory of operation is basic to all of them.

We will first review the construction and operation of the two-junction device. Then we will connect the transistor in circuits to show the various configurations with their own characteristic curves. Finally, we will discuss the "current transfer ratio" or control characteristics for each configuration.

The three elements of the two-junction transistor are: the emitter, which gives off current carriers (electrons or holes); the base, which controls the flow of the current carriers; and the collector, which collects the current carriers.

Classes of Transistors. Transistors are classed as P–N–P or N–P–N according to the arrangement of the N and P materials. Transistors have two junctions. One P–N junction is between the emitter and the base; the other P–N junction is between the collector and the base.

One type of junction transistor is formed by introducing a thin region of P-type material between two regions of N-type material in a single crystal of germanium or silicon. This is called an N–P–N transistor. By introducing a thin region of N-type material between two regions of P-type material, a P–N–P transistor is formed.

Exercises (479):

1. Name the parts of a transistor and state what each does.

2. Name the classes of transistors.

3. How is each class formed?

480. Describe the effect on a transistor when bias is connected to it.

Transistor Bias. In normal operation the emitter-base junction is forward biased and the collector-base junction is reverse biased. Forward bias at the emitter-base junction reduces the size and intensity of the emitter-base field. Therefore, the emitter-base junction is usually referred to as the "low resistance junction." Reverse bias at the collector-base junction increases the size of the collector-base field. Reverse bias opposes conduction by majority carriers; thus, the collector-base junction is referred to as the "high resistance junction."

Figure 7-4 is a diagram of two transistors showing the effect on the junction fields when the bias batteries are connected. The bias batteries are labeled V_{CC} collector voltage supply and V_{EE} for the emitter voltage supply. Notice that the forward bias (V_{EE}) reduces the junction field of the emitter-base junction, and that the reverse bias (V_{CC}) increases the junction field of the collector-base junction in both the N–P–N and P–N–P transistor. The basic current paths through an N–P–N transistor are illustrated in figure 7-5. The solid arrows indicate current flow due to free electrons. The dotted arrows indicate current flow due to hole movement (valence band electron movement). Current flow in the external circuit is always due to the movement of free electrons. Emitter current (I_E) is shown leaving the emitter supply battery and flowing to the N-type emitter. Since electrons are the majority carrier in N material, the electrons move through the emitter to the emitter-base junction field. Having gained energy from V_{EE}, the electrons overcome the small opposition of the forward-biased junction and are injected into the base region. The base region is P-type material, and the electrons are now minority carriers. As they move into the base region, some of them recombine with available holes. The electrons that recombine move out through the base lead as base current (I_B) and return to the emitter supply battery V_{EE}. Most of the electrons that move into the base region come under the influence of the collector-base junction field. The direction of the reverse-biased collector-base field is such that minority carriers are accelerated. The collector-base reverse bias is actually a forward bias condition for minority carriers in the base. Since the electrons are minority carriers at this time, they are accelerated through the field and injected into the collector region. The collector is N-type material and the electrons are again majority current carriers. The electrons now move through the collector material to the positive collector terminal. They then move out of the collector and return to the positive terminal of V_{CC} as collector current (I_C).

The basic current paths in a P–N–P transistor are shown in figure 7-5,B. The majority current carrier in the P–N–P transistor is the hole. Briefly, the method of transporting current through a P–N–P transistor is as follows: The energy from the emitter supply (V_{EE}) causes an electron-hole pair to be generated at the emitter terminal. The electron travels through the wire to the positive terminal of V_{EE} as emitter current, I_E. The hole travels through the transistor from emitter to collector. Upon reaching the collector terminal, the hole recombines with an electron from the negative terminal of the collector supply (V_{CC}).

While the current flow in the external circuit of the P–N–P transistor is opposite to that of the N–P–N, notice that regardless of the type of transistor, the majority carrier always moves through the transistor from the emitter to the collector.

Some holes, which are injected to the base by the emitter, recombine with electrons in the base. This recombination causes electrons to be drawn from the negative terminal of V_{EE}, through the base lead, into the N-type base material. The result is a small base lead current (I_B).

Exercises (480):

1. In normal operation, how are the two junctions of a transistor biased?

2. In an N–P–N transistor under normal operation, what happens to some of the electrons that move into the base region?

3. Briefly describe the current path in an N–P–N transistor when the correct bias is applied.

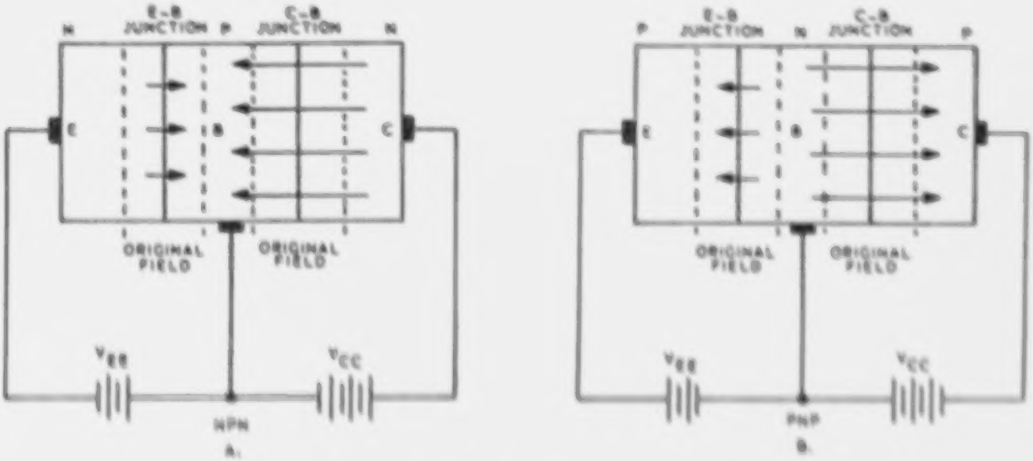

Figure 7-4. Biased transistors.

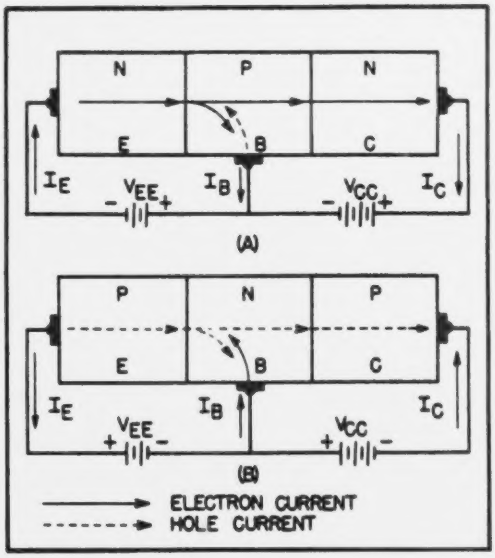

Figure 7–5. Bias current paths for N–P–N and P–N–P transistors.

4. Is current flow in the external circuit of the P–N–P transistor the same as, or opposite to, current flow of the N–P–N transistor?

481. Define drift and diffusion and state how they affect a transistor.

Drift and Diffusion. Whenever a current carrier comes under the influence of an electric field, it drifts in a predetermined direction. For instance, if a potential difference is applied to a piece of copper wire, current flows through the wire from the negative potential toward the positive potential. At any given instant, many of the electrons in the wire are moving in directions tangent, or even opposite, to the direction of the main current flow. In other words, the electrons do not move in a direct line from the negative to the positive potential but take a wandering path. The important point to remember is that when an electric field is established, more of the carriers move in a direction determined by the field than in other directions. By definition, drift current is the flow of charge carriers under the influence of an electric field.

A current flow also occurs if there is a difference in the density of the carriers between one area and another of a given material. If there are more carriers at one side of a piece of semiconductor material than at the other, there will be a charge flow from the side with greater density to the side with less density. If no external influences are applied, the carriers (electrons or holes) distribute themselves evenly throughout the material. Charge flow that takes place under these conditions is called diffusion current. As before, each individual carrier has an unpredictable random motion due to thermal energy, but when there is a difference in carrier concentration, more carriers move toward the area of less density than in any other direction. By definition, diffusion is a charge flow caused by an unequal density of charge carriers in a material.

The carriers that enter the base region and recombine are lost as far as collector current is concerned. Thus, for the transistor to be efficient, as many of the emitter carriers as possible must reach the collector region. If the base region is too wide, all the carriers injected into the base by the emitter recombine and leave the transistor as base current (I_B). The solution is for the base region to be very thin and lightly doped. This reduces the opportunity for a carrier to recombine and be lost.

The collector is physically larger than the base for two reasons: first, to increase the amount of collecting carriers that diffuse to the side as well as directly across the base region; and second, to give it a larger heat dissipation factor (explained later).

Exercises (481):

1. Define drift current.

2. Define diffusion.

3. In the construction of a transistor, why should the base region be very thin?

4. Give two reasons why the collector is physically larger than the base.

482. State the effects of bias on current flow in a transistor.

Transistor Currents. Understanding transistor currents is the key to understanding transistor operation. We now review the relative magnitude of bias voltages and currents.

Assume that an N–P–N transistor has .1 volt of forward bias across the emitter-base junction and 10 volts of reverse bias across the collector-base junction. The .1 volt reduces the width and heigth of the emitter-base junction barrier. The 10 volts increases the width and height of the collector-base junction barrier. For majority carriers, the emitter-base junction appears as a low resistance and the collector-base junction appears as a high resistance.

The N-type emitter has many free electrons in the conduction band. The P-type base has few holes because it is lightly doped. The holes are in the valence band. The N-type collector has many free electrons in the conduction band. The forward bias voltage allows some of the free electrons in the emitter to overcome the base-emitter barrier

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and enter the base, still in the conduction band. These electrons have been injected from the emitter into the base.

With the electrons in the base region, they become minority carriers. They now have two choices: to go on to the collector or stay in the base. To stay in the base, the electron must lose energy, fall from the conduction band into the valence band and recombine with a hole. This recombination of an electron and a hole results in base current (I_B).

Base current is small for two primary reasons. First, the base is made very thin to reduce the time allowed for possible recombination. Second, the base is lightly doped. If there are few holes in the base material, the chances of recombination are reduced.

Most of the injected carriers go on toward the collector junction barrier. The collector-base junction is forward biased for minority carriers (electrons in the base). The injected carriers see a forward-biased junction and readily move into the collector material; they have been injected from the base into the collector. When they arrive in the collector, the electrons again become majority carriers in the conduction band of the energy level diagram.

The relative magnitude of the currents in the leads of a transistor can be described in terms of percentage. Total transistor resistor current flows in the emitter lead, so I_E is 100 percent. Part of the current that enters the emitter goes to the collector and part of it goes to the base.

In a transistor with a base current of 1 percent, the collector current is 99 percent. Another example: consider a transistor that has 100 percent, 2 percent, and 98 percent current distribution in the emitter, base, and collector respectively, with an emitter current of 10 mA. Collector current would be 9.8 mA and base current would be .1 mA or 200 microamps. The emitter current is the sum of the collector current (I_C) and the base current (I_B). Likewise, I_C is equal to I_E minus I_B, or is equal to I_E minus I.

The fact that the emitter-base voltage is relatively small (with a correspondingly small base current) does not mean that it is unimportant. In general, emitter-base voltage can be considered the controlling factor for the transistor. Figure 7-6 shows the controlling effect that emitter-base voltage has on the transistor currents. Figure 7-6,A, shows an N–P–N transistor with .2 volt of forward bias and 10 volts of reverse bias. The simplified energy level diagram shows the height (H) and width (W) of the base-emitter junction barrier. Under these conditions a certain current will flow from the emitter to the collector (indicated by the arrow).

In figure 7-6,B, the forward bias voltage is increased to .3 volt. The increase in forward bias reduces the base-emitter junction barrier (H and W) and allows more carriers to reach the collector, causing an increase in current flow from the emitter to the collector.

Figure 7-6,C, shows what happens when the forward bias voltage is reduced to .1 volt. The emitter-base junction barrier increases in height and width and reduces the current from emitter to collector.

The conclusion that can be made is this: the relatively small emitter-to-base voltage controls the relatively large emitter-to-collector current. This is the basic reason for a transistor's ability to amplify.

The emitter-base voltage of a P–N–P transistor has the same controlling effect as that of a N–P–N, however, the energy level diagram is now inverted. Holes try to move upward in energy (electrons try to move downward in energy). For the holes in the emitter to be injected into the base material, they must cross the emitter-base junction barrier. The barrier has the height and width that represents an opposition to the carriers just like the barrier in the N–P–N transistor. Therefore, with .2 volt of forward bias, a certain current will flow from the emitter to the collector.

When the forward bias of the emitter-base junction is increased, the current from the emitter to the collector increases, because the forward bias has reduced the height and width of the junction barrier.

When the forward bias is decreased to .1 volt, the height and width of the emitter-base barrier increases and the current decreases from the emitter to the collector. Again,

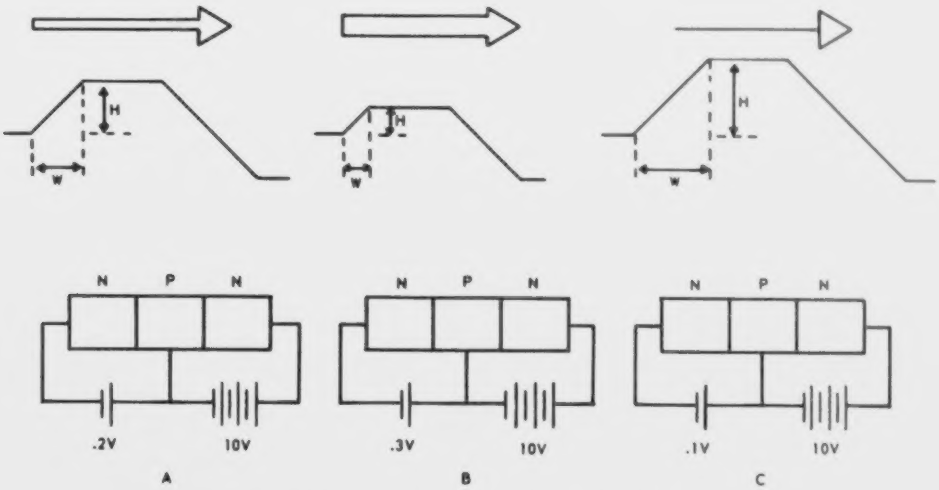


Figure 7–6. controlling effect of base-emitter voltage N–P–N.

the relatively small emitter-to-base voltage has a very large controlling effect on the emitter-to-collector current.

Although the current through a transistor can be controlled by the emitter-base voltage (V_{BB}), this control is nonlinear and does not give a clear picture of the actual transistor conditions. On the other hand, a clear and very desirable condition exists when the base current is used as the controlling factor. In transistor terminology, base current is used to indicate the controlling action in the transistor. This is called bias, which is defined as the average DC voltage or current used to control the operating point. In the operation of a semiconductor, bias is average DC current because these transistors are current-operated devices.

In figure 7-5,A, the electron current I_B in the base lead of an N–P–N transistor is shown to flow away from the base region. This drawing neglects the reverse current flow between the collector and base. If the emitter lead were open, a small reverse current would flow from the base to the collector. This current flow is called reverse-bias collector current, I_{CBO}. The letter I means current, the subscript O means emitter open. Thus, I_{CBO} means collector-to-base current measured with the emitter open.

The flow of I_{CBO} is opposite to the normal base lead current. However, under normal operating conditions, the magnitude of the reverse current is too small (in the microampere range) to subtract a significant amount from the base current. Under normal conditions, the base lead current for an N–P–N transistor flows toward the base. Remember that the base lead current for either type of transistor depends on the percentage of emitter current that recombines in the base region and the magnitude of the reverse current (I_{CBO}). The ambient temperature (heat) is the cause of I_{CBO}. As a general rule, I_{CBO} doubles in value for every 8° to 10° centigrade rise in temperature. Since the amount of I_{CBO} is determined by heat (forward bias has no control), the ambient temperature should be kept low.

Exercises (482):

1. When forward bias is applied to an N–P–N transistor, how does the emitter-base junction appear to the majority carriers?

2. What do electrons become once they have left the emitter of an N–P–N transistor and entered the base?

3. Why is base current normally small?

4. In which lead does total transistor current flow?

5. What is the controlling factor of a transistor?

6. In a transistor with the bias connected correctly, there is .7-volt forward bias. What will happen to the collector current if the forward bias voltage is reduced to .4 volts?

7. Why don't we get a clear picture of actual transistor conditions when we use emitter-base voltage to control current through a transistor?

8. Define bias.

483. State the direction of transistor current flow indicated by schematic symbols.

Transistor Symbols. The only difference between the P–N–P and N–P–N symbols is the direction of the arrow on the emitter lead. In the P–N–P, the arrow is pointing toward the base lead. In the N–P–N, the arrow is pointing away from the base lead. Current flows against the arrow as in P–N diodes. The external current in a P–N–P transistor is into the collector and out of the emitter. External current in an N–P–N transistor is into the emitter and out of the collector. In either case, the external current flows against the arrow on the emitter lead.

Figure 7-7 uses the schematic symbol of the N–P–N and P–N–P transistors with battery symbols to show the proper bias polarities and the current directions. Observe that the base-emitter junctions have forward bias and collector-base junctions have reverse bias. Figure 7-7,A, shows the P–N–P base voltage negative with respect to the emitter, and the collector voltage negative with respect to the base.

Figure 7-7,B, shows the N–P–N base voltage positive with respect to the emitter (forward bias) and the collector voltage positive with respect to the base (reverse bias).

Exercises (483):

1. Which way does external current flow in a transistor?

2. Which way does the arrow point in a P–N–P transistor symbol?

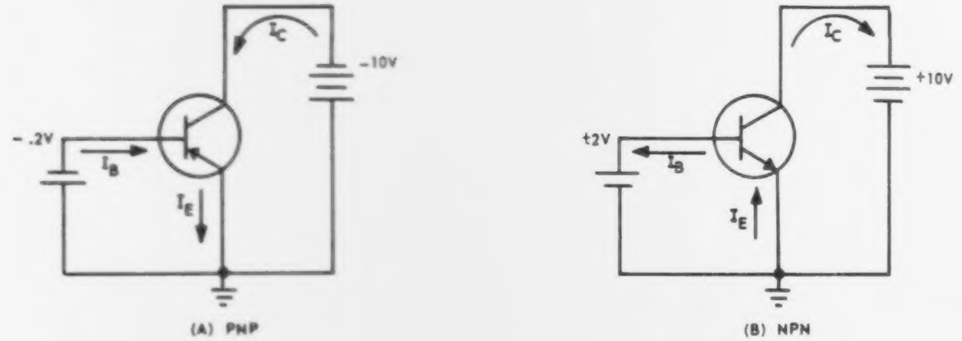


Figure 7-7. Bias polarities and current direction.

3. Which way does the arrow point in an N–P–N transistor?

484. State the basic transistor configurations and state the operation of each.

Transistor Configurations. A transistor can be connected in any one of three basic configurations: common-emitter,common-base, and common-collector. They are also called grounded-emitter, grounded-base, and grounded-collector. The common, or grounded, element is that element common to both input and output circuits. We discuss DC or statis operation of the three transistor configurations.

Grounded emitter configuration. Figure 7-8 illustrates the connections for both N–P–N and P–N–P transistors for a grounded emitter. The N–P–N transistor has a positive voltage ($+V_{CC}$), and the P–N–P transistor has a negative voltage ($-V_{CC}$) to satisfy the requirement for reverse bias between the collector and base. The forward bias for the emitter-base junction is provided by V_{CC} and R1 in series with the base-emitter junction. In both cases, the emitter of the transistor is grounded.

With forward bias applied, there are two direct current paths in these circuits. Figure 7-8,A, shows a path from ground into the emitter, out of the base lead, and through R1 to the positive V_{CC}. Another path is from ground into the emitter through the base and into the collector, and out of the collector to the positive V_{CC}. Figure 7-8,B, shows current paths for the P–N–P transistor. Notice that V_{CC} is now negative, and current flows from the power source to ground.

The characteristics of the grounded emitter junction amplifier can be summarized by the following list of major features. There is a signal-voltage phase reversal between the input and output. The grounded emitter has the highest current gain factor of the three basic connections. It also has a moderate input impedance and a moderate value of output impedance. It has a comparatively low response to high frequencies, and high values of power gain.

Grounded base configuration. Figure 7-9 illustrates a P–N–P and an N–P–N transistor biased for operation in a grounded base arrangement. The N–P–N transistor has a positive V_{CC} source voltage, which establishes the required reverse bias between the collector and base. The forward bias for the base-emitter junction is furnished by the minus V_{EE} source voltage. V_{CC} is about 10 volts and V_{EE} is tenths of volts. For the N–P–N transistor, current leaves the $-V_{EE}$ terminal and flows into the emitter. Part of this current leaves the base lead as base current I_B, and the remaining current leaves the collector lead as collector current I_C.

The P–N–P transistor (fig. 7-9,B) has a negative V_{CC} for the reverse bias between collector and base, and a positive V_{EE} for the forward bias between the base and emitter. Current flows into the collector and base leads, and out of the emitter lead.

A test circuit to obtain a family of characteristic curves for a common base configuration is shown in figure 7-10. Figure 7-11 shows the resulting characteristic curves. Notice that the emitter current is held constant, and collector current I_C is plotted against collector-to-base voltage V_{CB}. In a common base, then, emitter current is the controlling factor.

The forward current transfer ratio for a grounded base configuration is called alpha. This is the theoretical current gain of a grounded base configuration. You can compute

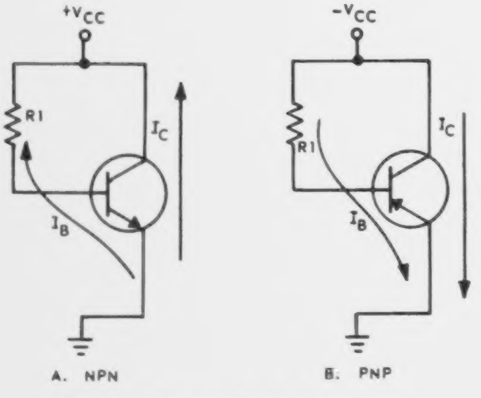


Figure 7-8. Grounded-emitter configuration.

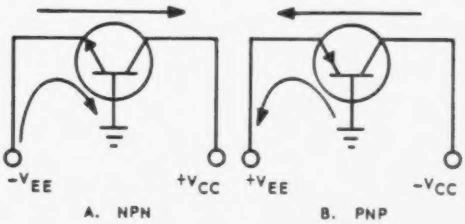


Figure 7–9. Grounded-base configuration.

alpha directly from the characteristic curves. Point A in figure 7-11 shows collector current to be 1 mA (approximately) and emitter current to be −1 mA. At point B, collector current is 1.9 mA and emitter current is −2 mA. Collector voltage is held constant at 10 volts. The change in emitter current is 1 mA, and the change in collector current is .9 mA. This results in alpha being .9, which is a gain of less than one. As you learned earlier, collector current equals emitter current minus base current. Alpha is a figure-of-merit. For example, an alpha of .99 indicates much more amplifying than an alpha of .95.

Next, compute how resistance changes with a change in emitter current. Point A represents 10,000 ohms (I_C = 1 mA and V_{CB} = 10 volts). Point B represents 5200 ohms (I_C = 1.9 mA and V_{CB} = 10 volts). For a change of 1 mA in I_E, resistance changes about 5000 ohms.

Most transistor manuals give either alpha or beta. To determine either quantity when the other is known, use the appropriate formula:

$$\beta = \frac{\alpha ce}{1 - \alpha ce}$$

or

$$\alpha = \frac{\beta}{1 + \beta}$$

For instance, if a transistor has an alpha of .95, determine the beta: (consider α and α_{ce} interchangeable).

$$\beta = \frac{\alpha ce}{1 - \alpha ce} = \frac{.95}{1 - .95} = \frac{.95}{.05} = 19$$

Also, what is the alpha of a transistor that has a beta of 99?

$$\alpha = \frac{\beta}{1 + \beta} = \frac{99}{1 + 99} = \frac{99}{100} = .99$$

The characteristics of the common-base circuit using a junction transistor are: low-input impedance, high output-circuit impedance, no voltage phase reversal between input and output, average gain of less than unity, good stability, and moderate power gain.

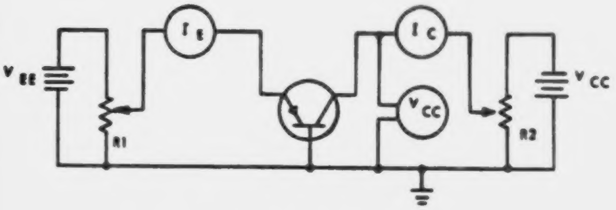


Figure 7–10. Grounded-base test circuit.

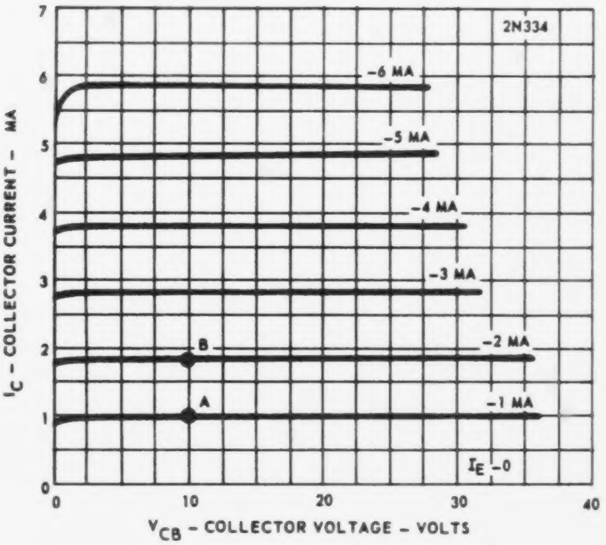


Figure 7–11. Plot of I_c versus V_{CB} with I_E constant.

Grounded collector configuration. Figure 7-12 shows the collector grounded and the proper bias, with the resulting current paths. One path is from ground through the emitter-to-base junction and through R1; and the other path is the emitter-collector current.

The common collector configuration is also called an emitter follower. The vacuum-tube equivalent is the cathode follower. Base current controls emitter current. A family of curves is seldom prepared for a common collector because the common emitter curves can be used. The main characteristics of the common collector transistor are low-output impedance, high-input impedance, moderate to high power gain, a voltage gain of less than unity, and no signal voltage phase reversal between input and output.

Exercises (484):

1. What are the three basic transistor configurations?

2. What is the phase of the input compared to the output of a common emitter?

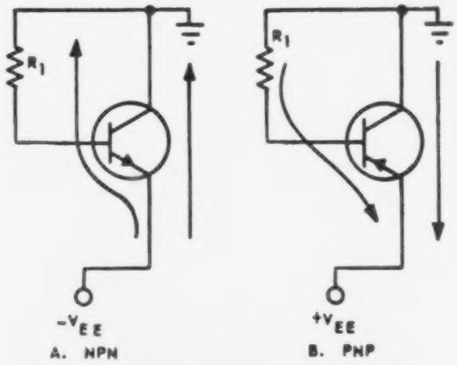


Figure 7-12. Grounded collector configuration.

3. How does the current gain of a grounded common emitter compare to the current gain of the other configurations?

4. What is the response of the common emitter to high frequencies?

5. What is the name for the forward current transfer ratio of a grounded-base configuration?

6. Characterize the input impedance of a common-base circuit.

7. Give the phase difference of the input compared with the output of the grounded-base transistor.

8. What is the common-collector configuration also called?

9. What is the signal voltage phase reversal between input and output of a common collector?

10. Characterize the input and output impedance of a common-collector transistor configuration.

485. Define a transistor characteristic curve and state the type information obtained from it.

Transistor Characteristic Curves. In the discussion of transistors up to this point, we have used only general terms to indicate the characteristics of semiconductors, such as small voltage, small current, large current, etc. Transistor circuit conditions and operations can be predicted much more accurately from characteristic curves. Characteristic curves are graphs, plotted to show the relationships of changing values. To develop transistor characteristic curves, we construct a circuit as shown in figure 7-13. Observe that base current and collector voltage are adjustable. Meters are connected in the circuit so that the currents and voltage can be monitored.

Let's first adjust resistor R_1 so that .1 mA (100 microamperes) of base current flows. This current would be indicated on the meter connected in the base lead. Now move the arm of R_2 to ground so that zero voltage is applied between the emitter and collector of the transistor. The collector circuit current meter indicates I_C as zero. We plot this as point one (P_1) on a graph of collector current (I_C) versus collector voltage (V_{CE}) shown 1n figure 7-14.

Now we adjust R_2 (fig. 7-13) until the voltmeter connected between the collector and the emitter indicates a V_{CE} of −1 volt, and adjusts R_1 to keep a base current of .1 mA. At this point I_C is about 8 mA, so we plot P_2 on the graph. We continue increasing the collector voltage by adjusting R_2, holding the base current constant by adjusting R_2, amd plotting the resultant collector current for points 3 and 4 in figure 7-14. Finally, we connect the plotted points with a line. The result is a line graph that shows the relation of I_C to V_{CE} (within the tested values when I_B is .1 mA.

We repeat the procedure for a new value of base current, such as .3 mA. By increasing the collector voltage in steps, and holding the base current at .3 mA, points P_5, P_6, and P_7 can be plotted as shown in figure 7-14.

We continue to plot for various values of I_B until a "family" of I_C to V_{CE} characteristic curves is developed. Figure 7-15 shows a family of curves for a 2N109 transistor used in a grounded emitter configuration. This chart does not hold true for any other type of transistor or any other configuration. We can use this family of characteristic curves to get specific operational values for a 2N109 transistor. We can determine the exact control that base current has on collector current.

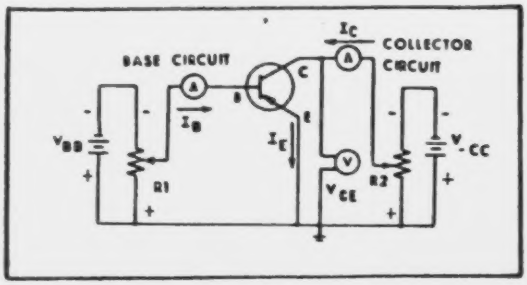


Figure 7-13. Characteristic curves test circuit.

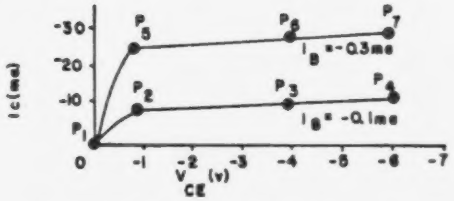


Figure 7-14. Plot of I_c verses V_{CE} with I_B constant.

With 3 volts on the collector (collector-to-emitter volts) and is approximately 9 mA. By changing base current to .3 mA, collector current has increased to approximately 26 mA (point B in fig. 7-15). With a change of .2 mA of base current (.3 mA minus .1 mA) collector current has changed 17 mA (26 mA minus 9 mA). This represents a controlling effect of 87 (17 mA divided by is called beta. By definition, beta is the forward-current transfer ratio of a common-emitter configuration. In other words, beta is the theoretical current gain (amplification) of a common-emitter configuration.

Collector voltage (V_{CE}) has very little control on collector current. We can illustrate this using figure 7-15. Holding I_B constant, with .1 mA of base current and collector voltage at 3 volts (point A), collector current is about 9 mA. By changing collector voltage to 9 volts (point C, fig. 7-15), collector current is about 11 mA. So, for a 6-volt change in collector voltage, collector current changes only 2 mA. You can see that collector voltage has very little control over collector current.

Another characteristic you can determine with transistor characteristic curves is how resistance changes with a given change in forward bias. For example, to determine the resistance at point A, figure 7-15, use the formula R = E/I. The collector voltage is 3 volts and collector current is 9 mA. This results in 333 ohms of resistance. Point B, figure 7-15, has about 115 ohms of resistance (collector voltage of 3 volts divided by collector current of 26 mA). For this particular transistor, a change of .2 mA in base current results in a resistance change greater than 50 percent.

Exercises (485):

1. How is a characteristic curve defined?

2. What type of information can you obtain from a characteristic curve?

486. State what makes up DC power supplies and cite important considerations in applying them.

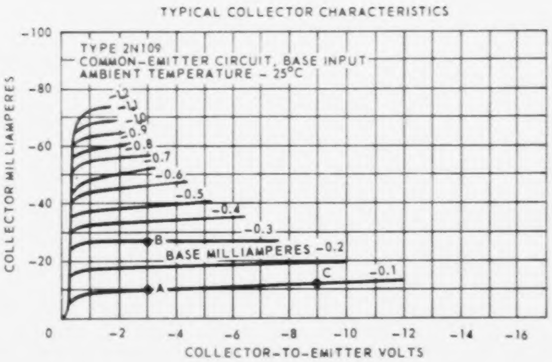


Figure 7-15. Transistor characteristic curves.

Power Supplies. Electronic circuits that contain transistors require various values of DC voltage. Batteries are suitable for supplying these voltages for some portable equipment, but a DC power supply as required for systems that operate frequently or for prolonged periods of time, as in the operation of aircraft AFCS systems. The elements commonly found in DC power supplies are an AC source, transformer, rectifier, filter, voltage divider, and voltage regulator. All power supplies do not contain all six of those elements. The only essential parts are the AC source and a rectifier; however, most power supplies use filters. Many DC power supplies for tranisstorized AC circuits contain only these three elements. The other elements help the power supply provide a wider range of output voltage, voltages that are smoother, or voltages that are more stable.

Rectifiers. Semiconductors are coming more and more into use in DC power supplies because they have (1) no requirement for filament power (with bulky and heavy filament transformers), (2) immediate operation with no warmup time, (3) low internal voltage drop that is relatively independent of load current, (4) low operating temperature, and (5) small physical size.

The single-phase half-wave rectifier is the simplest type of rectifier circuit. It consists of a diode in series with the AC source and the load. Figure 7-16 shows four basic

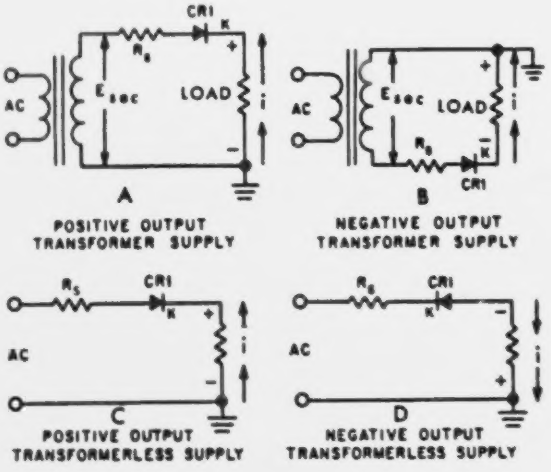
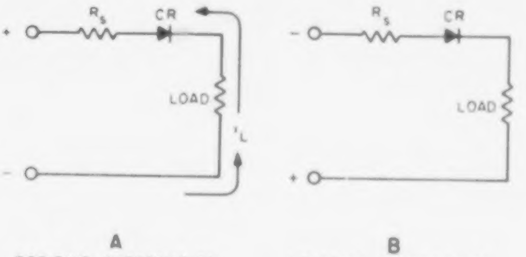


Figure 7-16. Basic half-wave rectifier circuit.

arrangements for a half-wave rectifier. Parts A and B show the use of a transformer for the AC source. The transformer is used for isolation or to step up the voltage for a higher output voltage. The isolation transformer permits either end of the output DC supply to be grounded so that the polarity of the output voltage is determined by the end of the output that is grounded. The two circuit variations shown in parts C and D of figure 7-16 operate directly from the AC source. In this case, the terminal of the AC source that is grounded must also be grounded in the DC supply.

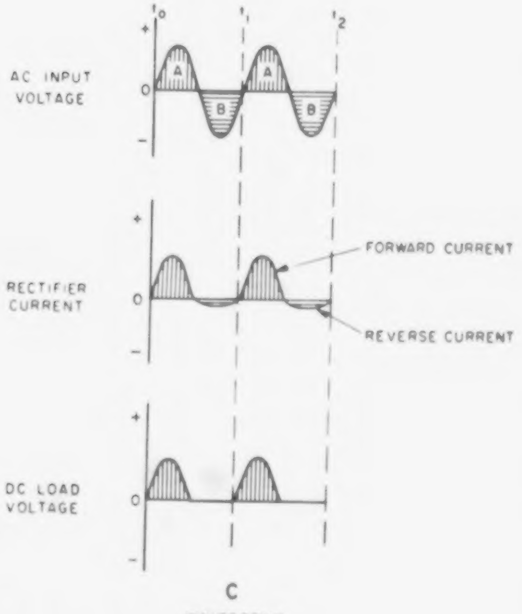
The diode is the same in all four circuits. The direction of current flow through the diode and the location of the ground terminal determine whether the DC output is positive or negative. Electron current flow is always against the arrow of a semiconductor diode rectifier.

Figure 7-17 shows the operation of a half-wave rectifier. The rectifier circuit is shown in parts A and B, and the waveforms are shown in part C. When the AC input voltage (top of part C) is in its positive alternation, the polarity at the output of the receifier is as shown in the rectifier current waveform, and current flows through the load as shown by the DC load voltage waveform. During the negative alternation, the polarity of the input to the rectifier is as shown in part B. A small amount of reverse current flows through a semiconductor, as you can see in the rectifier current waveform. This does not show up as an output in the DC load voltage waveform because the impedance of the rectifier is much larger than the load impedance during reverse bias. For all practical purposes, all the voltage is dropped across the rectifier. Resistor R_s shown in all the rectifiers in figures 7-16 and 7-17 is called a surge resistor. It limits the peak current through the rectifier to a safe value. The resistor may not be needed if the rectifier has a transformer input or a choke input filter.



A
POSITIVE ALTERNATION

B
NEGATIVE ALTERNATION



C
WAVEFORMS

Figure 7–17. Half-wave rectifier operation.

The half-wave rectifier produces an output voltage as shown in part C of figure 7-17. The frequency of this voltage is the same as the input voltage and requires filtering to smooth out the ripple and produce a steady DC voltage. Assuming that the output is filtered, the peak inverse voltage across the diode in a half-wave rectifier is approximately 2.83 times the RMS value of the applied (or transformer secondary) voltage.

The full-wave rectifier is one of the most common types of rectifier circuits used in electronic equipment. It is used in both low-voltage and high-voltage applications. The full-wave rectifier consists of a transformer with a center-tapped secondary winding, at least two diodes, and a load. At least one diode is connected at each end of the secondary winding, as shown in figure 7-18. The load is connected between the transformer center tap and the common junction of the two diodes. The diodes conduct on alternate half-cycles of the AC input voltage in the secondary of T_1 as shown in figure 7-18. The dashed arrows show the conductor of CR_1 and the solid line shows the center path for the conduction of CR_2. The current wave shape for each of the diodes is shown in part B of figure 7-18. Notice that current flows in only half of the transformer secondary at any one time and that current flow through the load is in the same direction all the time.

The full-wave rectifier circuit uses the transformer for a greater percentage of the time than a half-wave rectifier, and there are two pulsations of current in the load for each completed cycle of applied voltage, as shown by the DC load voltage wave shapes in figure 7-18. Since only half of the secondary winding is in use at any one time, the secondary voltage must be twice as much as for the half-wave rectifier in order to get the same power supply output voltage. However, the full-wave rectifier is more efficient since the transformer is in use all the time and there is less output ripple. This gives the full-wave rectifier better voltage regulation than a half-wave rectifier. With a filter, the peak inverse voltage across a diode in a full-wave rectifier circuit is approximately 2.83 times the voltage across half of the transformer secondary, or approximately 1.41 times the voltage across the entire secondary.

In a full-wave rectifier circuit designed for high-voltage output, the peak inverse voltage rating of the semiconductor diode is an important consideration. For this reason several diodes are sometimes placed in series to achieve the desired peak inverse voltage rating. These are usually shown as only one diode on schematics, however. Diodes are sometimes placed in parallel to obtain a higher current output from a power supply.

A single-phase full-wave bridge rectifier is shown in figure 7-19. (The inset at the right of fig. 7-19,A, shows an alternate method of drawing a bridge rectifier on schematics.) The full-wave bridge rectifier, commonly called a bridge rectifier, consists of a transformer, load, and four identical diodes. Its operation can be understood from the simplified circuit in figure 7-19. When the voltage in the secondary of T_1 is on the positive alternation (A in part B of the illustration), CR_2 and CR_3 conduct, as shown by the dashed arrows in part A; the current wave shape for CR_2 and CR_3 is shown in part B. When the negative alternation is on the T_1 secondary (B in the wave shapes shown in part B of fig. 7-19), CR_1 and CR_4 conduct, as shown by the solid arrows in part A. Figure 7-19,B, shows the current wave shape of CR_1 and CR_4. The output voltage wave shape, E_0, as shown at the bottom of part B. From the wave shapes given in figure 7-19,B, you can see that two rectifiers in series are conducting at any instant. On alternate half-cycles, current flow through the load resistor produces a pulsating output voltage with a ripple frequency that is twice the frequency of the AC voltage applied to the primary of the input transformer.

One advantage of the bridge rectifier over a full-wave rectifier is that, for a given transformer, the bridge rectifier produces nearly twice the output voltage of the full-wave rectifier. Another advantage is that the peak inverse voltage across an individual diode (when it is not conducting) is approximately half the peak inverse voltage across a diode in a full-wave rectifier designed to produce the same output voltage.

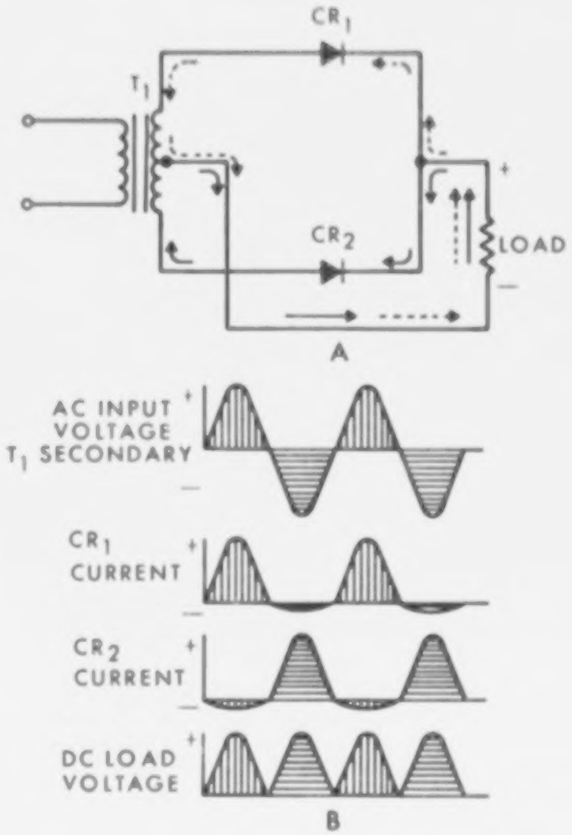


Figure 7-18. Full-wave rectifier operation.

Exercises (486):

1. What are the essential items for a DC power supply to operate?

2. What is the simplest type of rectifier?

3. In a half-wave rectifier, what does the direction of current flow through the diode and location of the ground determine?

4. What is used to produce a steady DC output of a half-wave rectifier?

5. What is the minimum number of diodes that can be used in a full-wave rectifier?

6. What is an important factor to consider when a full-wave rectifier circuit is designed for peak voltage output?

7. What is the output frequency of a full-wave bridge rectifier?

7-3. Multivibrators

A multivibrator is a circuit capable of developing a nearly rectangular waveform of any desired duration. When the circuit develops the desired waveform in response to an applied triggering of synchronizing pulse, the circuit is known as a driven, or synchronized, multivibrator. When

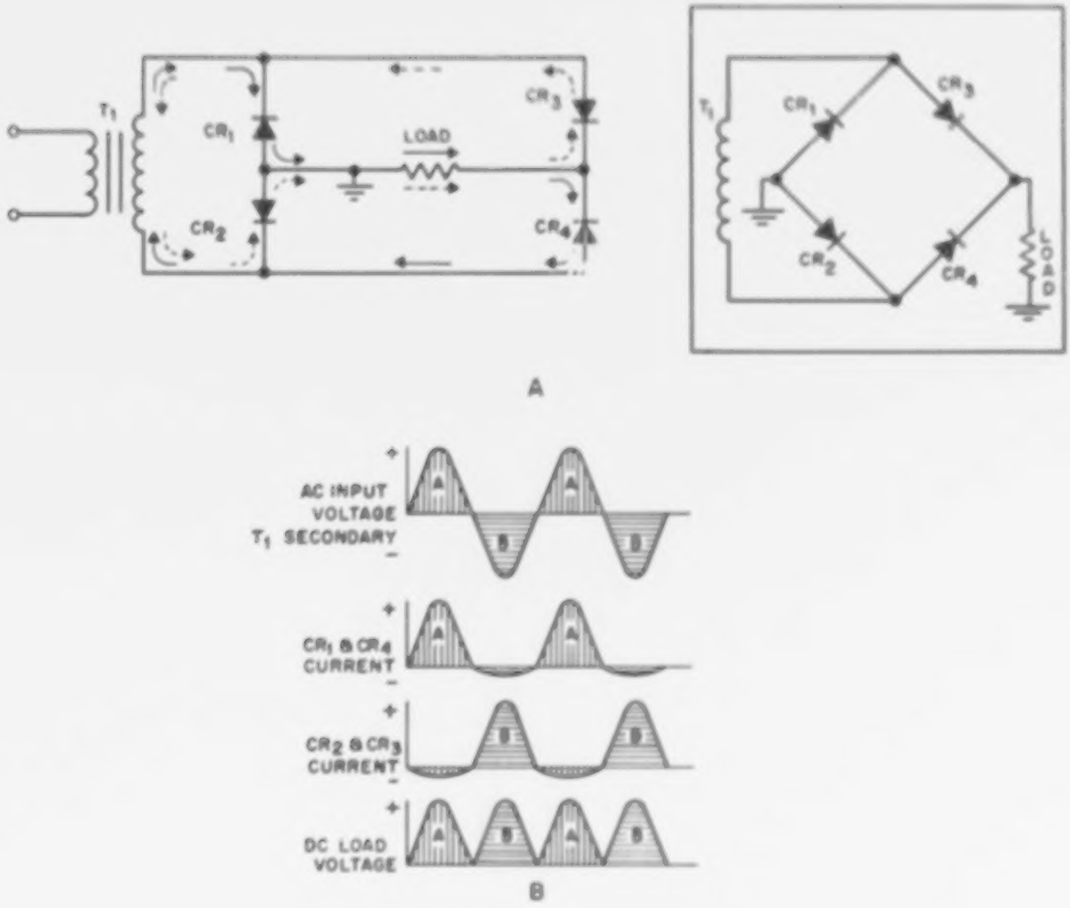


Figure 7-19. Full-wave bridge rectifier operation.

the circuit can develop a rectangular waveform independently of any other external triggering circuits, it is known as a free-running multivibrator. In this case, the frequency of operation depends entirely on the circuit constants of the multivibrator. The range of operation is fairly wide, beginning below the audio range and extending well into the radio-frequency range.

487. Identify the simplest multivibrator, and state how the transistors operate in a free-running multivibrator.

Free-running Multivibrator. The collector-coupled multivibrator is the simplest of the multivibrators. It produces an almost square wave when properly designed and a perfect square wave when additions are made in the basic circuit. In the schematic in figure 7-20, note that basically the multivibrator consists of two transistors. The output of the second stage is introduced back into the input of the first. The phase inversion through the circuit is 360°; any slight change in the first transistor is amplified through the circuit and causes a greater change in the same direction in the second transistor. That is, feedback is in phase and the circuit oscillates.

When voltage is applied to the circuit, current flows in both transistors. If the circuit components are the same in both transistor circuits and both transistors are of the same type, the circuit is said to be symmetrical, and both currents should be equal. It is impossible to get perfect balance in the circuit because of the nonuniformity of available parts and the irregular way emission occurs from the emitter. Any slight change in current in one transistor starts oscillations, producing a rectangular output wave shape.

Assuming that a slight current increase has occurred in the Q_1 of the multivibrator, let's analyze the action with the aid of the diagram shown in figure 7-20. The following events occur in rapid order. The increase of current in Q_1 increases the voltage drop across R_1, lowering the collector-to-ground voltage at Q_1. This lower voltage is now less than the charge on C_2, and capacitor C_2 discharges toward the new collector voltage (dotted arrows). The discharge current flows through R_4, making the base end negative. The negative base of Q_2 decreases the current through Q_2. This reduces both the collector current through Q_2 and the voltage drop across R_2, increasing the collector-to-ground voltage at Q_2. Capacitor C_1, between the collector and ground, therefore charges to the new higher

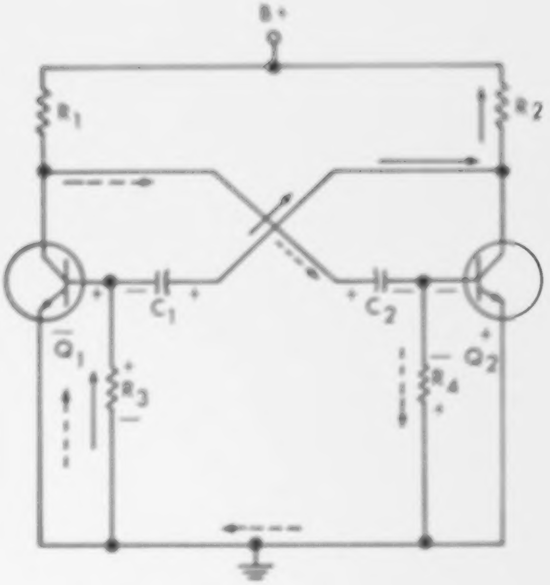


Figure 7-20. Multivibrator action when Q_1 conducts.

voltage. The charging current flows through R_3 toward the collector supply voltage (solid arrows in fig. 7-20). This current causes the top of R_3 and, therefore, the base of Q_1 to become more positive. The positive base causes the original slight increase in current to become a tremendous current increase. As the changes go around the circuit, a great voltage drop occurs at the collector of Q_1, the voltage on the base of Q_2 is decreased more, the collector voltage of Q_2 goes up, which makes the base of Q_1 more positive and further increases the Q_1 collector current.

This cumulative process continues until the current in Q_2 is decreased to zero by a base voltage far below cutoff. With zero current, the collector voltage of Q_2 becomes equal to B+ supply voltage, since there is no voltage drop across R_2. C_1 quickly charges to this value because of the base current flow in Q_1. The current through R_3 is now zero, so the base-to-emitter voltage is also zero. The collector voltage of Q_1 remains at a constant low value while the base-to-emitter voltage is zero; therefore capacitor C_2 continues to discharge to this value through R_4. While C_2 is discharging, the current (dotted arrows) holds Q_2 at cutoff. Everything remains at a standstill in the circuit except for the slow discharge of C_2.

The slow discharge of C_2 continues, and the voltage across C_2 becomes lower and lower. The voltage across R_4 (which equals the voltage across C_2 in accordance with Kirchhoff's voltage law) also decreases. Upon reaching a voltage just less than the cutoff voltage for Q_2, a slight current starts flowing through Q_2. This ends the period of conduction of Q_1 and nonconduction of Q_2. Swift changes follow this slight current, as directed in the following paragraphs.

When Q_2 conducts, the current through Q_2 lowers its collector voltage. C_1 starts to discharge through R_3 (dotted arrow in fig. 7-21), making the base of Q_1 more negative. The resulting decrease in collector current raises the collector voltage of Q_1. C_2 now recharges to the new Q_1 collector voltage through R_4. The charging current makes the base of Q_2 more positive, and the current through Q_2 is increased tremendously. This regenerative process continues, with the base of Q_1 going negative and the base of Q_2 going positive, until Q_1 is cut off by the discharge of C_1. At this point, Q_1 collector voltage rises quickly to the collector supply through Q_2 base current. At the same time, the collector voltage of Q_2 becomes steady at a low value. This ends the rapid changes during condition one.

A second inactive period occurs as Q_1 is held nonconducting by the slow discharge of C_1. The discharge continues until the C_1 voltage is just below cutoff for Q_1. The slight current in Q_1 builds up the same way as the current in Q_2, until Q_1 conducts heavily and Q_2 is cut off.

Exercises (487):

1. What is the simplest multivibrator?

2. What is the circuit said to be when both transistors and circuit components are of the same type?

3. Referring to the multivibrator of figure 6-20, when Q_1 stops charging and Q_2 starts charging, what happens to the bases of Q_1 and Q_2?

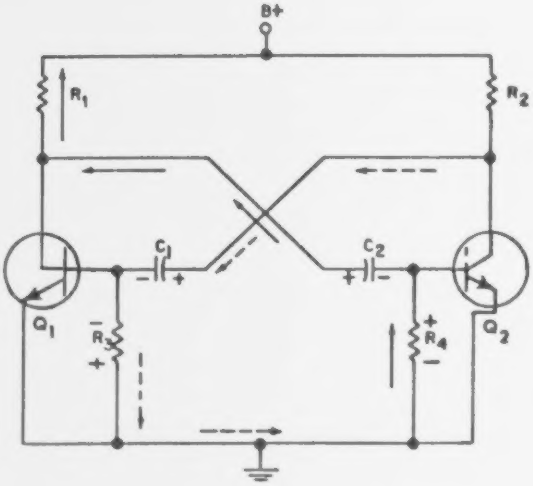


Figure 7-21. Multivibrator action when Q_2 conducts.

488. State the output frequency and the basic operation of a one-shot multivibrator.

One-Shot Multivibrator. The one-shop multivibrator is a widely used circuit, which never becomes free running and must always be triggered for each output pulse. It consists essentially of a two-stage resistance-capacitance-coupled amplifier with one transistor cut off and the other conducting (fig. 7-22).

The balance of the circuit is established by the arrangement for biasing the transistors. The base of Q_2 is connected to its emitter through resistor R_2. The emitter of Q_2 is connected to the emitter of Q_1. As Q_2 conducts, the voltage drop across R_k biases Q_1 to cutoff. If Q_1 is not conducting, Q_1 cannot be cut off by the self-bias developed across R_k. The following steps of the one-shot multivibrator produce the wave shapes shown. From time T_D to time T_1, Q_2 is conducting heavily. Its base is at emitter potential, and Q_1 is cut off by the voltage drop produced across R_k by the collector current of Q_2. Therefore, the collector voltage of Q_1 is at B+, and the collector voltage of Q_2 is considerably less than B+.

At time T_1, a positive trigger pulse, ample to raise the base Q_1 above cutoff voltage is applied to the base of Q_1 through C_1. Q_1 begins to conduct, and the voltage at its collector decreases. This decrease passes through C_2 (the voltage across a capacitor cannot be changed instantaneously) and appears across R_2 as a negative-going voltage on the base of Q_2. This negative-going voltage on the base of Q_2 decreases the current through Q_2, and the voltage drop across R_k decreases. This decrease in bias allows more current to flow in Q_1 and further decreases the collector current of Q_1, driving the base of Q_2 still more negative. This action is instantaneous and cumulative until Q_2 is cut off and Q_1 starts conducting. The switch from Q_1 to Q_2 is practically instantaneous as you can see from the wave shapes.

The circuit remains with Q_1 conducting and Q_2 cut off during the interval from T_1 to T_2, while C_2 discharges sufficiently toward the lowered value of collector voltage to allow the base of Q_2 to rise from its lowest value to cutoff voltage. At time T_2, Q_2 begins to conduct. The collector of Q_2, flowing through R_{lk}, raises the emitter voltage of Q_1 and causes its collector current to become less. The decreased collector current of Q_1 causes the collector voltage of Q_1 to increase sharply. This sudden rise in collector voltage is coupled to the base of Q_2, increasing its collector current still further. This flow of current through R_k biases Q_1 beyond cutoff. The collector voltage of Q_1 rises to B+ instantaneously, but C_2 is being charged at the same time (as shown from time T_{22} to T_3).

The circuit has now come back to its original balanced state and will remain so until another positive pulse arrives and causes Q_1 to conduct at time T_4. Note that every positive trigger pulse which causes Q_1 to conduct results in a large positive-going pulse from the collector of Q_2 and a negative-going pulse from the collector of Q_1. The length of output pulses produced is controlled by the time constant C_2R_2. If the resistance of R_2 (or the capacitance of C_2) is increased, the length of the output pulse is increased. An output pulse is produced for each input trigger pulse.

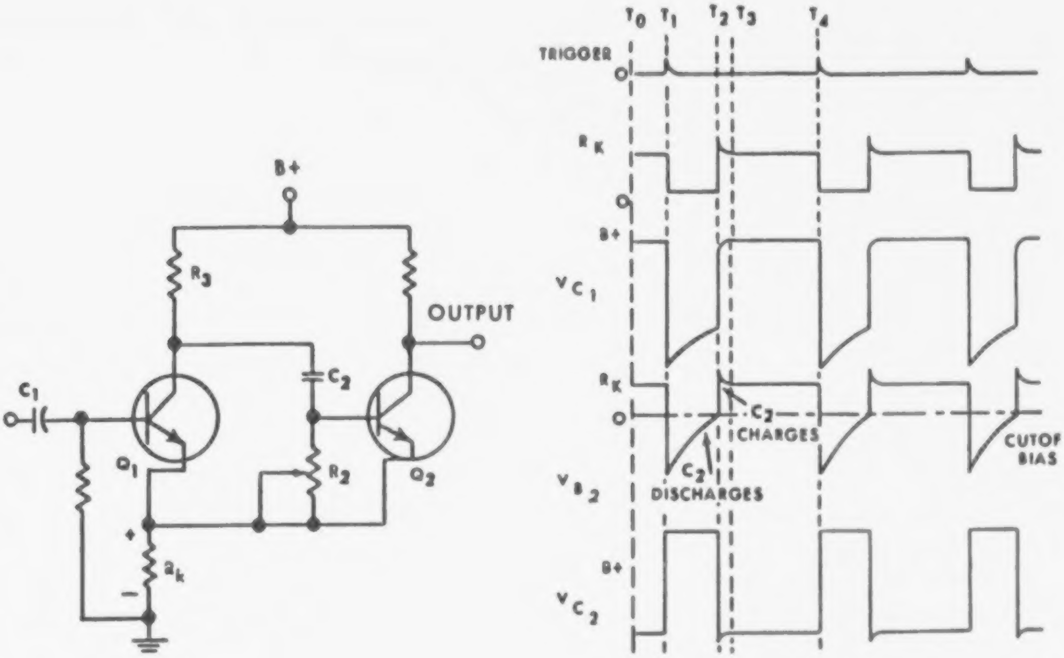


Figure 7-22. One-shot multivibrator and wave shapes.

Exercises (488):

1. Explain why a one-shot multivibrator will never become free running.

2. What is the output frequency of a one-shot multivibrator?

458

Analog Computers

WE ARE ALL AWARE of the ever-increasing importance of that miraculous unseen force—electricity. As you know, many years ago man learned how to put electricity to work. But those early inventors couldn't possibly forsee the almost limitless applications of electricity to labor-saving devices, and, most important to us, the analog computer. Electrical signals representing such flight factors as fuel consumption, aircraft altitude, gross weight, and engine thrust are used as inputs to various computers. The outputs of the computers are reflected in the various aircraft instruments, giving the pilot visual indications of actual flight.

The analog computer, simply stated, makes an analogy of constantly varying inputs. An analogy is a likeness to or a representative of something.

In this chapter you will study some of the different components and circuits that the computers use in solving equations. These components include synchromechanisms, resolvers, and switches.

8-1. Resolvers

There are several types of resolvers. However, for our discussion we are going to consider only the two most common, the magnetic resolvers and the potentiometer resolvers. They both accomplish the same job, but in a little different manner.

489. State the purpose of resolvers and, given pertinent conditions, calculate the output voltages of one- and two-phase magnetic resolvers.

If you look up the definition of a resolver, you will find that it is an instrument that performs the function of resolution. The term "resolution" indicates a process of reducing two or more quantities to a simpler form. For our purpose, we can say that a resolver solves equations. The resolver is frequently used to compute a voltage representing an angle such as pitch, bank, rudder, and aileron deflection. As an example, in the case of bank, a resolver computes a voltage dependent on the bank angle. This voltage feeds the bank angle servosystem, thereby creating a bank indication for the pilot.

Magnetic Resolvers. A magnetic resolver, as you may suspect, is similar to a transformer in that it works on the principle of magnetic induction. In fact, the illustrations used to explain magnetic resolver operation are similar to diagrams of transformers except that the secondary is variable. Since you have studied magnetic induction in an earlier chapter, we shall not discuss it in detail here. Sometimes there may be two secondaries 90° apart; but as a starter, let's stick with one secondary. A single-secondary, or single-phase, magnetic resolver is shown in two extreme positions in figure 8-1.

When the rotor is positioned at an angle of 0°, or parallel with the stator, as shown in figure 8-1,A, maximum output is felt at the rotor terminals because the coefficient of coupling is at maximum. The opposite effect occurs in figure 8-1,B. When the axes of the two coils are at an angle of 90° to each other, the magnetic field induced from stator to rotor is at minimum because the coefficient of coupling is decreased to minimum (in fact, the output voltage is, for all practical purposes, zero). Between these two extremes, the coefficient of coupling varies between maximum and minimum, depending on the coupling angle.

The relationship between the angular position of a resolver rotor and the voltage induced in it is shown in figure 8-2. The position of the rotor is depicted at each 45° of shaft rotation in detail A. Detail B is a graph representing the induced voltage.

Starting at zero degrees, the coupling is maximum and the induced voltage plotted in figure 8-2,B, is high. As the rotor turns through quadrant I, the graph shows a continual decrease in induced voltage. When the rotor is turned beyond 90° into quadrant II, the voltage begins to increase at the same rate that the decrease occurred in quadrant I.

In quadrants II and III of figure 8-2,B, the voltage curve is below the base line. This is the result of a reversal of the rotor (a change of phase relationship). If you relate your earlier knowledge of transformer phase dots to resolvers, the reason for a phase change should be apparent. In figure 8-2,A, where the rotor is positioned as shown in quadrants II and III, the phase dots on the rotor are opposite those on the stator. In quadrant IV of figure 8-2,A, the phase dots are again in phase with the stator; therefore, the voltage curve reappears above the base line in quadrant IV of figure 8-2,B.

One other point before we proceed to the two-rotor resolver. The resolver output in figure 8-2,B, looks like a sine wave; however, you may remember from an earlier volume that it is really a cosine wave. In order to produce both a sine and cosine wave from a magnetic resolver, we need to add another rotor.

A two-phase resolver, shown in figure 8-3,B, has a sine winding mounted 90° from a cosine winding on the rotor. Since the two windings are attached to the same shaft, the two outputs are always 90° apart.

If the cosine output starts at maximum, the sine output must start at minimum. The graphic result is shown in figure 8-3,C. Note that at 45° the sine and cosine voltage lines cross; the sine voltage is increasing and the cosine decreasing. Also notice that at 45° the outputs are not one-

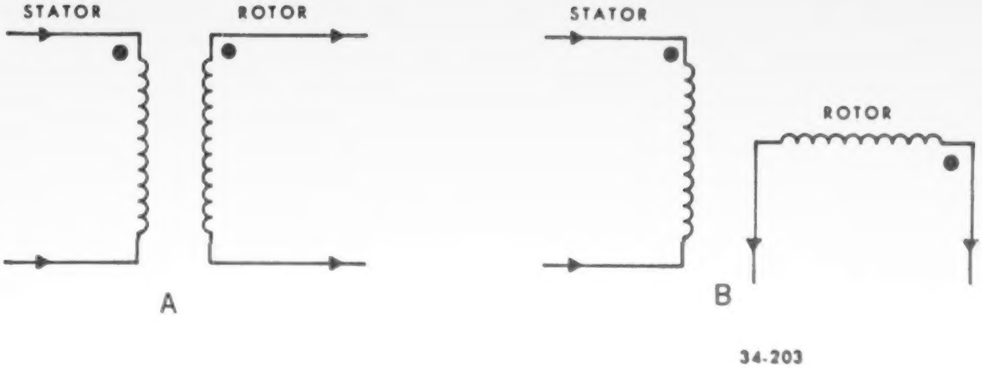


Figure 8-1. Maximum and minimum resolver output.

half maximum amplitude. By consulting a trigonometry table, you will find the sine and cosine output to be 0.707 of maximum at 45°. As an example, if the maximum output from the sine and cosine windings is 25 volts, then the output from either winding at 45° should be slightly over 17.5 volts. Note too that 0.5 of maximum voltage (12.5 volts, using 25 volts as maximum) from the sine windings occurs at 30°. The cosine output is 0.5 of maximum at 60°. You can determine the approximate outputs for any angle by examining the voltage curves in figure 8-3,C. One point that may not have been made clear is that when the resolver is stationary at any angle, the outputs are also steady.

Now, let's see how a two-phase resolver is used to produce signals representative of the groundspeed and the vertical speed on an airplane maneuver. Figure 8-3,A, portrays an aircraft coming from the left and pulling up into a loop. Before the aircraft goes into a loop, the cosine output, representing groundspeed, is at maximum. Of course, the sine output, representing vertical speed, has to be at minimum (zero) during straight and level flight.

When the aircraft noses up at a 45° angle, the groundspeed (cosine) signal decreases (because less distance is traveled over the ground), and vertical speed (sine) must increase. As you follow the aircraft through the loop, relate the aircraft attitude in detail A to the outputs from each winding shown in detail C for a better understanding of the relationships.

You should keep in mind that in the example of an aircraft going through a loop, a voltage representing true velocity of the aircraft is applied to the stator. Also, true velocity will vary at different stages of the loop. The output then of the sine and cosine windings is a percentage of the true velocity voltage applied to the stator during that portion of the loop.

Notice the changes in phase and amplitude as the aircraft comes around in the loop. Notice also that after the loop is completed, the outputs are back to their original conditions.

The function of the magnetic resolver is to produce an output varying according to the trigonometric function of an angle. Another type of resolver, the potentiometer (pot) type, can also produce this same output, or it can produce other types of varying outputs.

Potentiometer Resolvers. The output of the pot-type resolver depends mainly on its design, which can vary in many ways. Pot-type resolvers may be constructed similar to the special-wound pots described in an earlier section, or

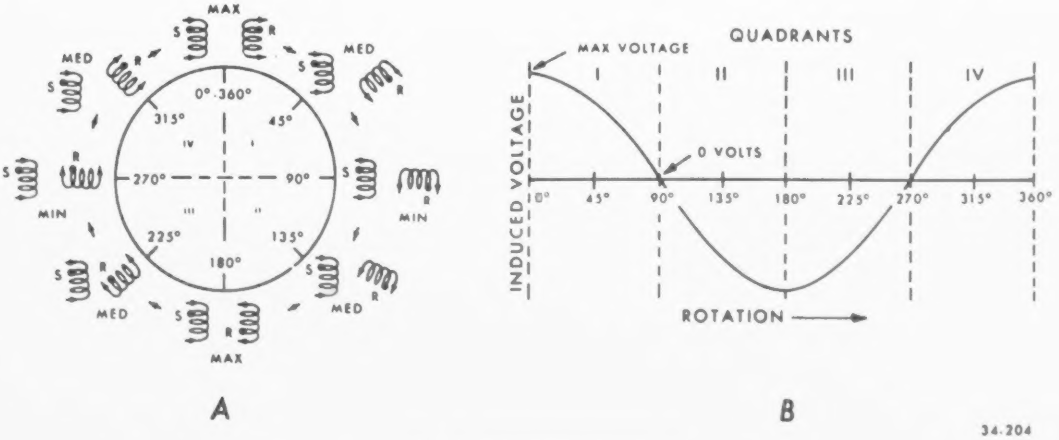


Figure 8-2. 360° of resolver rotor rotation.

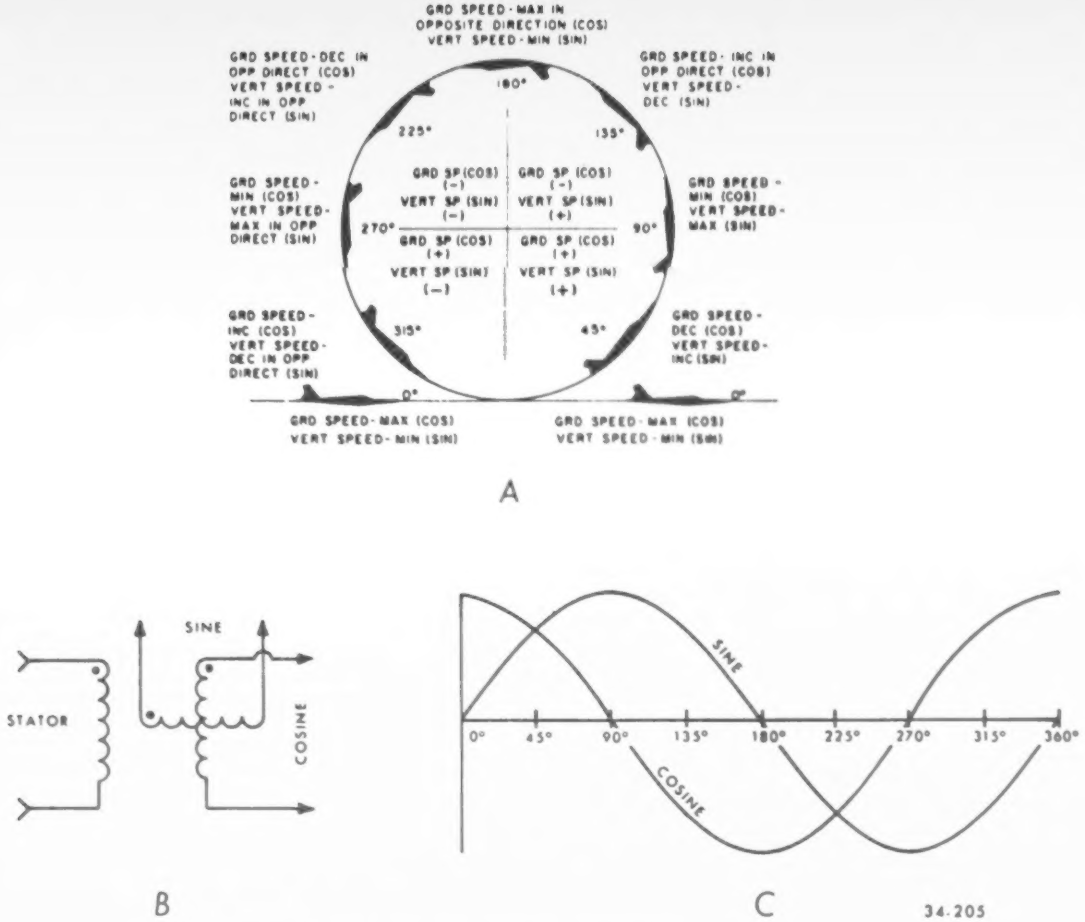

GRD SPEED - MAX IN OPPOSITE DIRECTION (COS) VERT SPEED - MIN (SIN)
GRD SPEED - DEC IN OPP DIRECT (COS) VERT SPEED - INC IN OPP DIRECT (SIN)
GRD SPEED - INC IN OPP DIRECT (COS) VERT SPEED - DEC (SIN)
180°
225°
135°
GRD SP (COS) (−)
VERT SP (SIN) (−)
GRD SP (COS) (−)
VERT SP (SIN) (+)
GRD SPEED - MIN (COS) VERT SPEED - MAX IN OPP DIRECT (SIN)
270°
90°
GRD SPEED - MIN (COS) VERT SPEED - MAX (SIN)
GRD SP (COS) (+)
VERT SP (SIN) (−)
GRD SP (COS) (+)
VERT SP (SIN) (+)
GRD SPEED - INC (COS) VERT SPEED - DEC IN OPP DIRECT (SIN)
315°
45°
GRD SPEED - DEC (COS) VERT SPEED - INC (SIN)
0°
0°
GRD SPEED - MAX (COS) VERT SPEED - MIN (SIN)
GRD SPEED - MAX (COS) VERT SPEED - MIN (SIN)
A
SINE
STATOR
COSINE
B
SINE
COSINE
0°
45°
90°
135°
180°
225°
270°
315°
360°
C
34.205

Figure 8–3. Two-phase resolver's output related to an aircraft.

they may resemble conventional linear pots; from their outputs appearence, you may not recognize them immediately as being resolvers.

There may be anywhere from two sets of brushes (four contact points) to a single brush producing one output. The sample shown in figure 8-4 is a two-brush pot-type resolver. This type of resolver produces an output similar to that of a two-phase magnetic resolver.

If the resolver is special wound and designed to faithfully reproduce sine (and cosine) wave shapes, the output will be like that shown by the curved dotted lines in figure 8-4,B. On the other hand, if the windings are linear, the output is a straight-line approximation of a sine or cosine curve, represented by the solid lines in figure 8-4.

An approximation of a sine (and cosine) wave by use of linear pot-type resolvers is somewhat easier to produce than true sine and cosine waves. Although faithful reproductions of sine and cosine wave shapes are normally desired, there are (in some cases) advantages in using straight-line approximations. In some cases, approximations of sine and cosine waves work better than true reproductions. In other cases, the function using the output may not be critical; consequently, the linear pot-type resolver will do the job at less cost. The selection of a resolver will depend largely on the type of circuit in which it is to be used.

Exercises (489):

1. For what purpose are resolvers used?

2. A single-phase magnetic resolver's rotor is positioned at 0° and a charge of 50 volts is applied to the stator. What is the output voltage?

3. A two-phase magnetic resolver's cosine winding is set at 60° and has 50 volts applied to the stator. What is its output voltage?

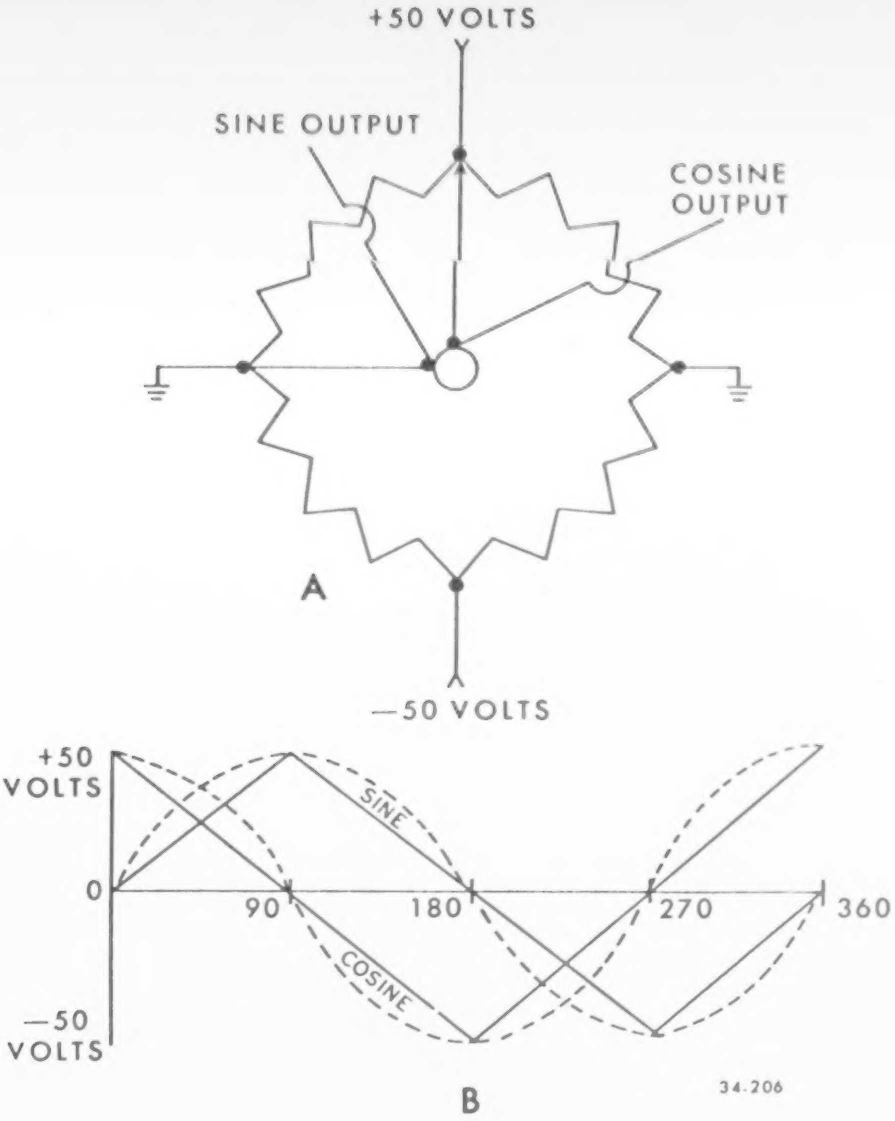

+50 VOLTS
SINE OUTPUT
COSINE OUTPUT
A
—50 VOLTS
+50 VOLTS
0
—50 VOLTS
SINE
COSINE
90
180
270
360
B
34-206

Figure 8–4. Potentiometer-type resolver.

4. If 50 volts is applied to the stator of a two-phase magnetic resolver, and if the cosine winding produces 50 volts output, what is the voltage output of the sine winding?

5. What is the difference between the outputs from a magnetic resolver and a linear pot resolver?

8-2. Switches

Many of the circuits in a system require that a circuit be either opened or closed at a particular point in the rotation of a servoshaft. The switching operation is accomplished by a plunger-operated switch actuated by a cam. One of the early plunger-operated switches in wide use carried the trade name "Microswitch"; today, this trade name is used as a common designator for any plunger-operated switch.

490. State the function and operation of cam-operated switches.

Cam-Operated Switches. The cam to operate the switch is mounted on the servoshaft and actuates the switch at selected positions of shaft rotation. In some cases, however, a small motor drives the cam continuously at a fixed speed.

The cams are made either of metal or of a phenolic-type material. Generally the metal cams have adjustable detents; the phenolic cams have fixed detents.

Adjustable detent cams. The dip, or hollow portion, of the cam shown in figure 8-5 is the detent, and, as shown here, it is adjustable. When the lockscrew is loosened, the two disks can be moved to change the width (angular degrees) of the detent opening. In the example shown in figure 8-5, the microswitch roller is in the detent and thus allows the switch to make contact between terminals 1 and 2.

Although there are numerous types and shapes of adjustable cams, they all function in much the same manner as our example. A lockscrew is cut into the disks to allow detent adjustment. The width and number of detents on a cam are determined by the circuit it controls.

The locknut on the shaft is used to lock the cam or cams to the shaft after they have been synchronized. If slippage occurs between the cam and the shaft, the switch will not operate at the proper time. After you determine which circuit is affected, follow the TO procedure for adjustment.

A cam driven by a servo may rotate any number of degrees for 1° of servo dial rotation. Generally, the adjustable cam operates a switch only once during each revolution; but others, not adjustable, may operate the switch two or more times per revolution.

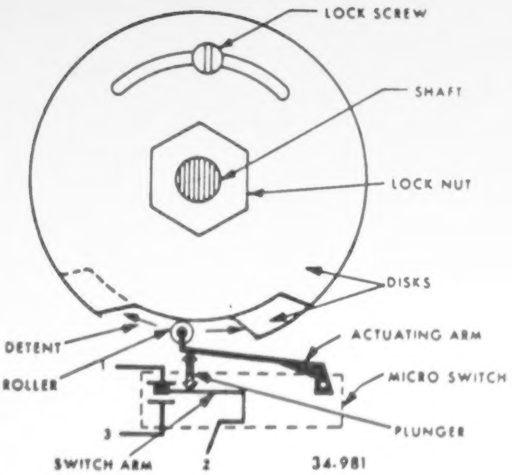


Figure 8-5. Cam and micro switch.

Switch action. The switch operated by the cam is a small unit mounted on a bracket. As shown in figure 8-5, a roller rides the face of the cam. Through the actuating arm, the cam depresses, or releases the plunger to actuate the switch. The switch itself normally has two or more fixed contacts and a movable contact. The movable contact, or switch arm, is spring loaded to the up position. It is actuated to the down position when the actuating arm moves out of the detent. With the roller on the high portion of the cam, there is continuity between terminals 2 and 3; with the arm in the detent, as shown, there is continuity between terminals 1 and 2. Usually terminal 2 is used as a ground and completes a circuit connected to either terminal 1 or terminal 3.

In order to set the length of time that the ground is present for either terminal 1 or terminal 3, you must adjust the width of the cam's detent. At the same time, you must synchronize the cam position to a specified shaft position. Specifications for each cam and switch are listed in the applicable technical order.

Exercises (490):

1. What is the function of the cam on the cam-operated switch?

2. What happens if the locknut allows a cam to slip on its shaft?

8-3. Synchromechanisms

We shall conclude this chapter by discussing one more component of the analog computer—the synchromechanism. Synchromechanisms, or self-synchronous motors, have a wide variety of trade names, such as selsyn, autosyn, and telesyn. The preferred name, however, is synchro, which is used for the various types described in this section.

491. State the purpose of synchros.

Synchros. The term "synchro" is an abbreviation of the word "synchronous." It is the name given to a variety of rotary, electromechanical, position-sensing devices. Synchros may be used to convert mechanical shaft angles to electrical signals or electrical signals to mechanical shaft degrees.

A synchro resembles a small electrical motor in size and appearance and operates like a variable transformer. The synchro, like the transformer, uses the principle of electromagnetic induction.

Synchros are used primarily for the rapid and accurate transmission of information between equipment and stations. The speed and accuracy of the transmitted information are most important. Synchros can provide this speed and accuracy. They are reliable, adaptable, and compact. Figure 8-6 shows a simple synchro system which can be used to transmit different types of data. In this system a single synchro transmitter furnishes two synchro receivers with information. These receivers are placed in spaces that require the transmitted information.

In the above system, the information to be transmitted is applied by turning the handwheel. This in turn rotates the transmitter shaft, which has a dial attached to indicate the value of the transmitted information. When the synchro transmitter shaft is turned, it converts the mechanical input into an electrical signal which is sent by way of interconnecting wiring to the two synchro receivers. The receiver shafts rotate in response to the electrical signal from the transmitter. When these shafts turn, the dials attached to the shafts indicate the transmitted information.

By using a simple synchro system, you can see that information can be transmitted over long distances, from one location to another, or from one piece of equipment to another.

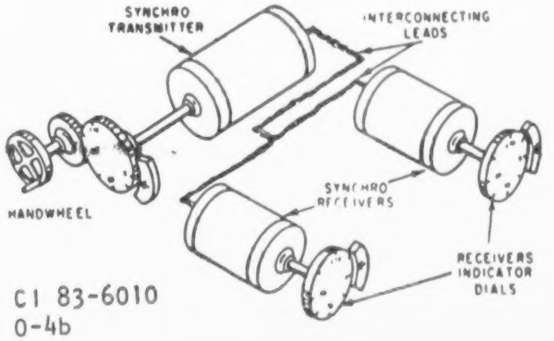


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Figure 8-6. Data transfer with synchros.

Another example of a use to which synchros are put is illustrated in figure 8-7. Note that one synchro is geared to, and driven by, the antenna motor. It is called the synchro generator or transmitter, because as its rotor turns with the antenna, it generates and transmits electrical voltages to another synchro which, at everyinstant, represent the position of the antenna. The second synchro is called a synchro motor or receiver, because it receives the output of the synchro generator. The voltages received by the receiver synchro exert a force on its rotor which, in turn, causes it to align itself and the cathoderay tube (CRT) deflection coil with which it is geared with the rotor of the transmitting synchro. Thus, the two synchros enable the CRT deflection coil and the antenna to rotate in perfect synchronism, even though they may be very far removed from one another.

Exercises (491):

1. What is the name given to a wide variety of rotary, electromechanical, position-sensing devices?

2. What is the primary purpose of a synchro system?

491a (511—for CE feedback reference only). Identify classifications of synchros.

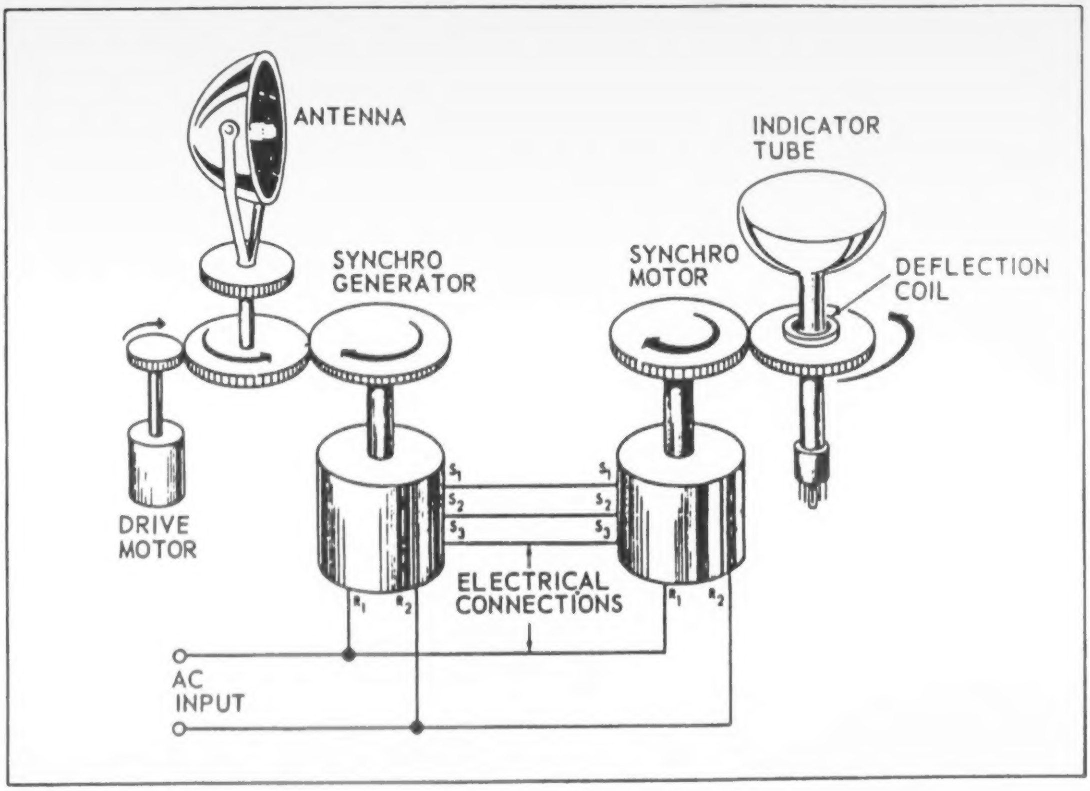
Synchro Classification. Synchros work in teams. Two or more synchros interconnected electrically form a synchro system. There are two general classifications of synchro systems—TORQUE SYSTEMS AND CONTROL SYSTEMS. Torque-synchro systems use torque synchros and control-synchro systems use control synchros. The load dictates the type of synchro system, and thus the type of synchro.

Torque-synchro systems are classified as "torque" because they are mainly concerned with the torque or turning force required to move light loads such as dials, pointers, or similar indicators. The positioning of these devices requires a relatively low amount of torque. Control synchros are used in systems which are designed to move heavy loads such as gun directors, radar antennas, and flight controls.

Each synchro is described in table 8-1 by name, abbreviation, input, output, and other synchro units connected to it. Generally, torque and control synchros may not be interchanged. The functional operation of each of these synchros is covered later in this text.

Table 8-2 will be needed later for zero and maximum voltage values.

Synchros are also classified according to their operating frequency. This classification has been brought about by the development of the 400-Hz synchro. Prior to this time,


ANTENNA
INDICATOR TUBE
SYNCHRO GENERATOR
SYNCHRO MOTOR
DEFLECTION COIL
DRIVE MOTOR
S1
S2
S3
S1
S2
S3
R1
R2
R1
R2
ELECTRICAL CONNECTIONS
AC INPUT

CI 83-6011
0-4b

Figure 8-7. Simple synchro system.

TABLE 8-1
SYNCHRO INFORMATION

FUNCTIONAL CLASSIFICATION	ABBREVIATION	INPUT	OUTPUT
Torque transmitter	TX	Mechanical input to rotor (rotor energized from AC source).	Electrical output from stator representing angular position of rotor supplied to TR.
Control Transmitter	CX	Same as TX.	Same as TX supplied to CT.
Torque Receiver	TR	Electrical input to stator from TX (Rotor energized from AC source).	Mechanical output from rotor. NOTE: rotor has mechanical inertia damper.
Control transformer	CT	Electrical input to stator from CX mechanical input to rotor.	Electrical output from rotor proportional to the sine of the angle between rotor position and angle represented by electrical input to stator. Called error signal.

CI 83-6135
0-4b

the 60-Hz synchro was the only one in use. Synchro operating frequencies are covered in detail in the section on synchro characteristics.

Exercises (491a):

1. What are the two general classifications of synchro systems?

2. What is the basic difference between a torque synchro and a control synchro?

3. Name one type of synchro which provides a mechanical output.

491b (512—for CE feedback reference only). Interpret synchro identification markings.

Synchro Identification. The military standard designation code identifies standard synchros by their physical size, functional purpose, and supply voltage characteristics. The code is alphanumerical and is broken down in the following manner. The first two digits indicate the diameter of the synchro in tenths of an inch to the next higher tenth. For example, a synchro with a dimension of 1.75 inches uses 18 for the first two digits. The first letter indicates the general function of the synchro and of the synchro system—C for control or T for torque. The next letter indicates the specific function of the synchro, as follows:

LETTER	*DEFINITION*
D	Differential
R	Receiver
T	Transformer
X	Transmitter

If the letter "B" follows the specific function designation, it indicates that the synchro has a rotatable stator. The last number in the designation stands for the operating frequency—6 for 60 Hz and 4 for 400 Hz. If a lower case letter follows the frequency designation, a modification to the synchro is indicated. Successive modifications are in alphabetical order.

TABLE 8-2

SYNCHRO MINIMUM AND MAXIMUM VALUES

Meter Connected Between	Zero Voltage Headings	Maximum Voltage Headings
S1 and S2	120°, 300°	30°, 210°
S2 and S3	60°, 240°	150°, 330°
S1 and S3	0°, 180°	90°, 270°

The rotor voltages should remain constant at all times, either 115 volts or 26 volts. In a system where the units are close enough to permit checking, the voltage between the R1 and R2 terminal of any unit energized by the primary AC source and the corresponding R1 or R2 terminal of any other unit energized by the primary AC source should be zero. When the excitation voltage (115 volts or 26 volts) is above or below the nominal value, the maximum stator voltages will also be above or below normal.

For example, an 18TR6 synchro is a 60-Hz torque receiver with a diameter of between 1.71 and 1.80 inches. This is broken down as:

18 — Synchro diameter of 1.71 to 1.80 inches
T — Torque
R — Receiver
6 — 60 Hz

A synchro designated 16CTB4b is the first modification of a 400-Hz control transformer with a rotatable stator and a diameter of between 1.51 and 1.60 inches.

16 — Synchro diameter of 1.51 to 1.60 inches
C — Control
T — Transformer
B — Rotatable stator
4 — 400 Hz
b — First modification (a indicates the original or basic issue)

All standard synchros are labeled with this code. Synchros used in circuits supplied by 26 volts are classified in the same way, except that the symbol 26V is prefixed to the designator (for example, 26V-16CTB4a). Otherwise, a 115-volt source is assumed for the synchro system.

Exercise (491b):

1. What does the code 26V-11TX4d mean on a synchro nameplate?

491c (513—for CE feedback reference only). Interpret synchro schematic symbols.

Schematic Symbols. Schematic symbols for synchros are drawn by various manufacturers in many different ways. Only five symbols (as shown in fig. 8-8), however, meet the standard military specifications for schematic diagrams of synchro and synchro connections. Appearing close to the symbol is a military abbreviation of one of the seven functional classifications of synchros (such as TR, TX, TDX, etc.).

The symbols shown in views (A) and (B) of figure 8-8 are used when it is necessary to show only the external connections to a synchro, while those shown in views (C), (D), and (E) are used when it is important to see the positional relationship between the rotor and stator. The letters R and S, in conjunction with a numerical quantity, are used to identify the rotor and stator connections; for example, R1, R2, S1, S2, and S3. The small arrow on the rotor symbol indicates the angular displacement of the rotor. In figure 8-8 the displacement is 0°.

Exercises (491c):

1. On an electrical schematic, what indicates the angular displacement of a synchro rotor?
2. When are the coils shown in the symbol for a synchro?

491d (514—for CE feedback reference only). List the parts of a synchro.

Synchro Construction. The knowledge of how a synchro is constructed should enable you to better understand synchro operation.

Figure 8-9 shows a cutaway view of a typical synchro. The main points to be discussed are the rotor and stator construction and how the synchro is assembled. Each synchro contains a rotor, similar in appearance to the armature in a motor, and a stator which corresponds to the field in a motor. The synchro stator is composed of three Y-connected windings (S1, S2, and S3). The rotor is composed of one single winding (R1 and R2). As can be seen in the figure, the rotor winding is free to turn inside the stator. The rotor is usually the primary winding and receives its voltage (excitation) from an external voltage source. The stator receives its voltage by magnetic coupling from the rotor.

Rotor construction. There are two common types of

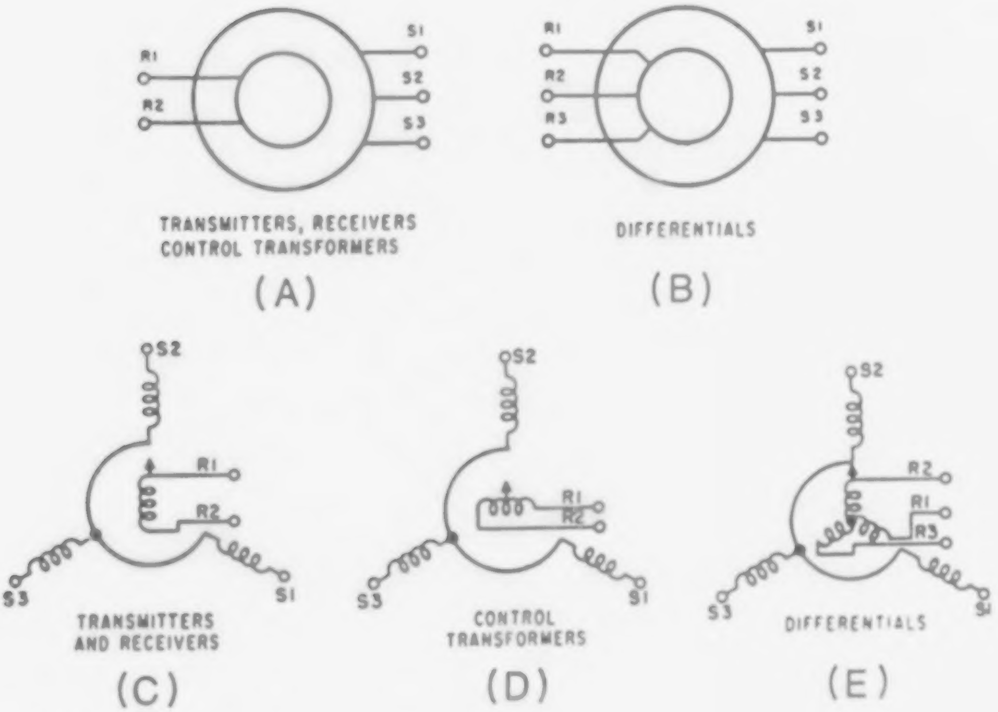


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Figure 8-8. Schematic symbols for synchros.

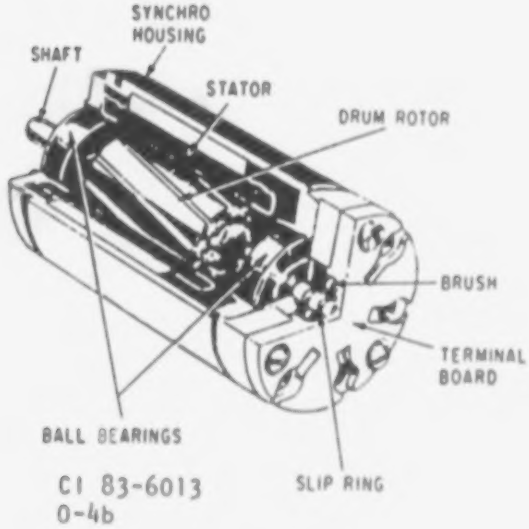

Figure 8-9. Typical synchro assembly.

synchro rotors in use—the SALIENT-POLE ROTOR and the DRUM or WOUND ROTOR. The salient-pole rotor shown in figure 8-10 has a single coil wound on a laminated core. The core is shaped like a "dumbbell" or the letter "H." This type of winding is frequently used in both transmitters and receivers.

The drum or wound rotor has coils wound in slots in a laminated core as shown in figure 8-11. The drum or wound rotor is used in most synchro control transformers and differential units, and occasionally in torque transmitters. This type of rotor may be wound continuously with a single length of wire or it may have a group of coils connected in series. The single continuous winding provides a distributed winding effect for use in transmitters. When the rotor is wound with a group of coils connected in series, a concentrated winding effect is provided for use in control transformers.

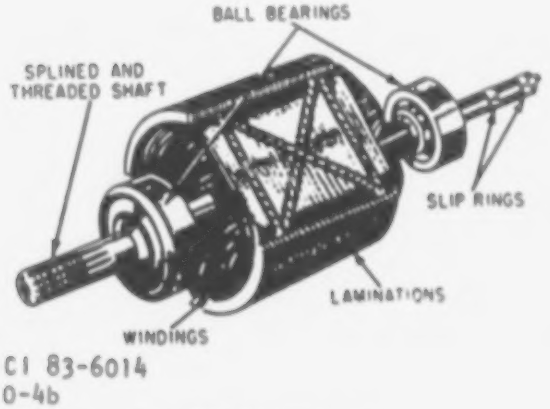

Figure 8-10. Salient-pole rotor.

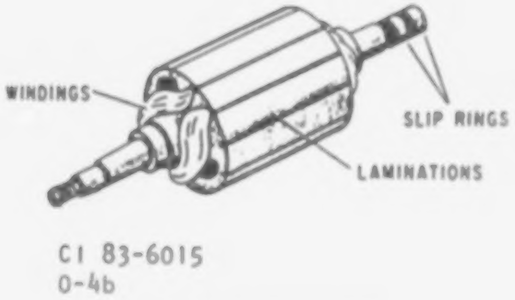

Figure 8-11. Drum or wound rotor.

Both of these synchro rotors have their coils wound on laminated cores which are rigidly mounted on a shaft. To enable the excitation voltage to be applied to the rotor winding, two slip rings are mounted on one end of the shaft and insulated from the shaft to prevent shorting. An insulated terminal board mounted on the end of the cylindrical frame houses the brushes which ride on the slip rings. These brushes provide continuous electrical contact to the rotor during its rotation. Also mounted on the rotor shaft are low-friction ball bearings which permit the rotor to turn easily.

Stator construction. The stator of a synchro is a cylindrical structure of slotted laminations on which three Y-connected coils are wound with their axes 120° apart. Figure 8-12(A) shows a typical stator assembly which consists of the laminated stator, stator windings, and cylindrical frame; (B) shows the stator lamination and the slots in which the windings are placed. Some synchros are constructed so that both the stator and the rotor may be turned. Electrical connections to this type of stator are made through slip rings and brushes.

Now, look back at figure 8-9 for a view of a completed synchro assembly. The rotor has been placed in the stator assembly. A terminal board has been added to provide a point at which internal and external connections are made.

Exercises (491d):

1. What are the two major components of a synchro?

2. Which of the two types of rotors can have either a single winding or three Y-connected windings?

3. How does the stator receive its voltage?

4. Where are the external connections made on standard synchros?

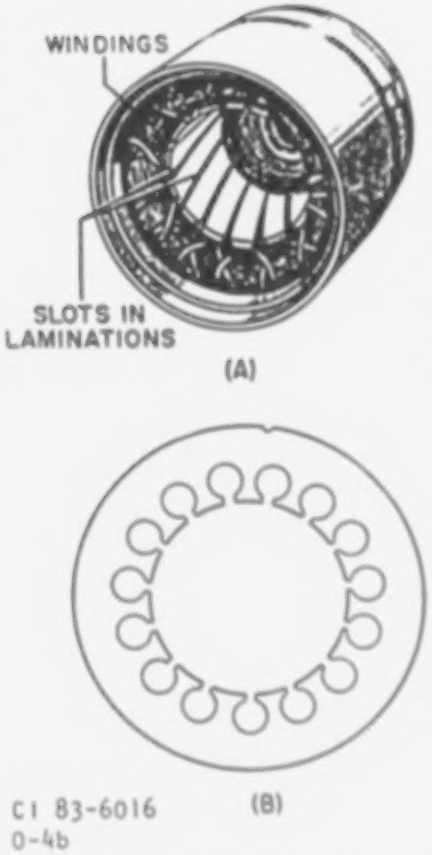

Figure 8-12. (A) Typical stator; (B) stator lamination.

491e (515—for CE feedback reference only). Identify characteristics of synchros.

Synchro characteristics play a very important part in synchro troubleshooting and maintenance. By closely observing these characteristics, you can generally tell if a synchro or synchro system is working properly. Low torque, overheating, and improper operating voltages are just a few of the abnormal characteristics found in synchro systems.

Torque. Torque is simply a measure of how much load a machine can turn. In torque synchros, only small loads are turned; therefore, only a small amount of torque is required. The measure of torque is the product of the applied force and the distance between the point of application and the center of rotation. For instance, if a 3-ounce weight is suspended from a synchro pulley having a radius of 2 inches, the torque required to move the weight is 6 ounce-inches. In heavy machinery, torque may be expressed in pound-feet, but torque synchro measurements are in ounce-inches.

NOTE: The unit of torque is the pound-foot or ounce-inch. This should not be confused with a foot-pound, which is the measurement of work. Many times in referring to torque, tools are marked in foot-pounds. While this use of foot-pounds is technically incorrect, common usage has made it acceptable.

The torque developed in a synchro receiver results from the tendency of two electromagnets to align themselves. Since the rotor can be turned and the stator usually cannot, the stator must exert a force torque which pulls the rotor into a position where the primary and the secondary magnetic fields are in line. The strength of the magnetic field produced by the stator determines the torque. The field strength depends on the current through the stator coils. As the current through the stator is increased, the field strength increases and more torque is developed.

In ordinary synchro applications, the receiver shaft follows the transmitter shaft with a high degree of accuracy and is rarely more than 1° in error. For this reason a unit based on a 1° displacement, and known as the TORQUE GRADIENT, is used when rating torque synchros. If, for example, the torque gradient of a snychro is given as 0.5 ounce-inch per degree, it would mean that a torque of 0.5 ounce-inch would pull the receiver rotor 1° away from the transmitter rotor. For small angles, the torque increases linearly, and a torque of 2 ounce-inches would pull the shafts 4° apart (2÷0.5 = 4°). The torque gradient is usually included in the design specifications of a synchro.

The torque gradient is the best measurement of the accuracy of a synchro system. If the torque gradient decreases, the accuracy decreases. The torque gradient decreases when (1) more receivers are added to the system, (2) when the mechanical load on the receiver units is increased, or (3) when there is an increase in the synchro operating temperature. Therefore, the load capacity of a synchro system is limited by the number and types of receiver units loading the transmitter, the loads on these receiver units, and the operating temperature.

Operating Voltages, Frequencies, Temperatures, and Speeds. Military standard synchros are designed for use on either 115 volts or 26 volts. Aircraft use mostly 26-volt synchros. The operating voltage and frequency are marked on the nameplate of each synchro.

Synchros are also designed to operate on a 60- or 400-Hz frequency, but like transformers, they are more efficient at the higher frequency. Operating a synchro unit at a higher frequency also permits the synchro unit to be made physically smaller. This is because the lines of flux produced by the 400-Hz excitation voltage are much more concentrated than those produced by the 60-Hz excitation voltage. Hence, the core size of the 400-Hz synchro can be made smaller than the core size of the 60-Hz synchro. However, some 400-Hz synchro units are identical in size to their 60-Hz counterparts. This is done so that 60- and 400-Hz units can be physically interchanged without special mounting provisions.

The use of the smaller size synchro permits the construction of smaller and more compact equipment.

The most widely used frequency specification for airborne equipment is 400 Hz. Aircraft instrument systems use 400-Hz synchros exclusively.

A synchro that is designed for a 60-Hz operation may occasionally be used with a 400-Hz supply. There may be considerable loss of accuracy, but no damage to the synchro will result. This should be done only in the case of an emergency when the specified replacement is not available and when system accuracy is not critical.

CAUTION

NEVER connect a 400-Hz synchro to 60-Hz voltage. The reduced impedance results in excessive current flow and the windings quickly burn out.

Operating Temperatures and Speeds. Standard synchros are designed to withstand surrounding temperatures ranging from −67°F to +257°F (−55°C to +125°C). When a synchro is energized and not loaded, its temperature should stay within prescribed limits. Loading an energized synchro causes it to generate more heat. Similarly, overloading causes a synchro to generate much more heat than it would under normal loading conditions and could possibly result in permanent synchro damage. To meet military specifications, all standard synchros must be capable of continuous operation for 1,000 hours at 1,200 revolutions per minute (rpm) without a load.

Exercises (491e):

1. Define the term "torque."

2. What unit of measurement is used when referring to the torque of a synchro transmitter?

3. What are the major factors which determine the load capacity of a torque-synchro transmitter?

4. Why is torque gradient the best measurement of the accuracy of a synchro system?

5. What type of equipment normally uses 26-volt 400-Hz synchros?

6. When will a synchro generate more heat than it is designed to handle?

491f (516—for CE feedback reference only). Describe the theory behind the operation of synchros.

Theory of Operation. Synchros, as stated earlier, are, in effect, variable transformers. They differ from conventional transformers by having one primary winding (the rotor) which may be rotated through 360° and three stationary secondary windings (the stator) spaced 120° apart. It follows that the magnetic field within the synchro may also be rotated through 360°. If an iron bar or an electromagnet were placed in this field and allowed to turn freely, it would always line up in the direction of the magnetic field. This is the basic principle underlying all synchro operations.

This discussion of synchro operation will begin with a few basic points on the electromagnets. We will use figure 8-13 to illustrate this. In this figure 8-13, a simple electromagnet is shown with a bar magnet pivoted in the electromagnet's field. In view (A) of the figure, the bar is forced to assume the position shown, because the basic law of magnetism states that like poles of a magnet repel and unlike poles attract. Also notice that when the bar is in alignment with the field, the magnetic lines of force are shortest. If the bar magnet is turned from this position and held as shown in view (B), the flux is distorted and the magnetic lines of force are lengthened. In this condition, a force (torque) is exerted on the bar magnet. When the bar magnet is released, it snaps back to its original position. When the polarity of the electromagnet is reversed, as shown in view (C), the field reverses and the bar magnet is displaced 180° from its original position.

Keeping in mind these basic points, consider the reaction of the bar magnet to three electromagnets spaced 120° apart as illustrated in figure 8-14. In this figure, one end of each of the coils is connected to a common point.

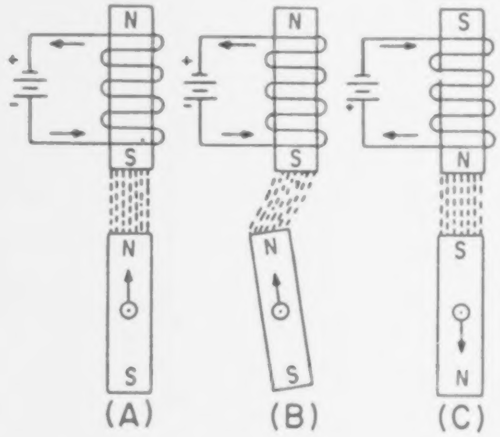

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Figure 8-13. Operation of an electromagnet with a bar magnet rotor.

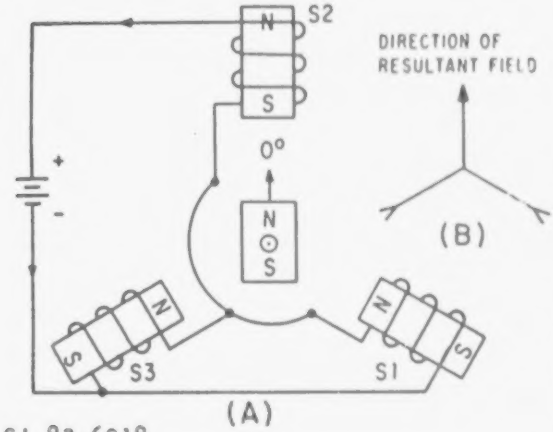

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Figure 8-14. Operation of three electromagnets spaced 120° apart.

The other end of each coil is connected to a battery. The strongest magnetic field is set up by stator coil S2 because it has the total current flow through it. Therefore, it follows that stator coils S1 and S3 contain one-half the field strength of that of S2 since they receive one-half of the total current. A resultant magnetic field is developed as a result of the combined effects of the three stator fields. S2 has the strongest field, and thus, the greatest effect on the resultant field and causes it to align in the direction shown by the vector in view (B) of the figure. The iron-bar rotor aligns itself within the resultant field at the point of greatest flux density as shown. By convention, this position is known as the 0° (electrical zero) position. The rotor can be turned from this position to any number of positions by applying the proper combination of voltages to the three coils as illustrated in figure 8-15.

Notice in figure 8-15, views (A), (C), and (E), the rotor positions are achieved by shifting the total current through different stator windings (S1, S2, and S3). This causes the rotor to move toward the coil with the strongest magnetic field. To obtain the rotor positions in views (B), (D), and (F), it was necessary only to reverse the battery connections. This caused the direction of current flow to reverse and, in turn, reversed the direction of the magnetic field. Since the rotor followed the magnetic field, the rotor also changed direction. By looking closely at these last three rotor positions, you will notice that they are exactly opposite the first three positions discussed. This is caused by the change in the direction of current flow. You can now see that by varying the voltages to the three stator coils, the current in these coils will change and cause the rotor to assume any position desired. It is helpful in the study of synchros to analyze first the operation of the DC selsyn.

Referring to figure 8-16, on the right you will see a bar magnet which is free to turn in a magnetic field produced by three iron-core coils placed 120° apart. Instead of using a battery, the three coils are energized from voltages at three taps on the circular potentiometer to the left of the figure. The potentiometer is, in turn, energized by a battery whose terminals connect to the potentiometer by means of two sliding contacts.

The sliding contacts are insulated from one another and, when moved, move in unison. It is important to note that the outer taps on the potentiometer are 120° apart and

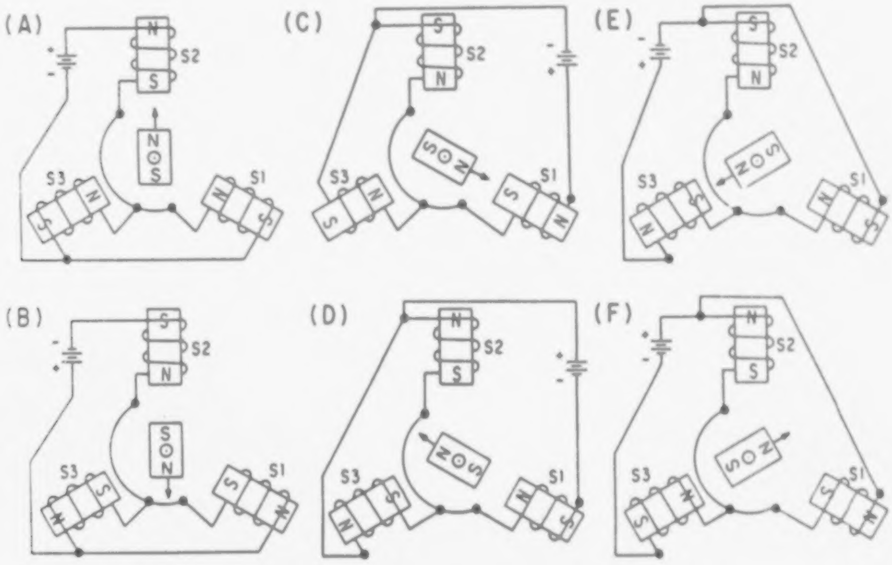

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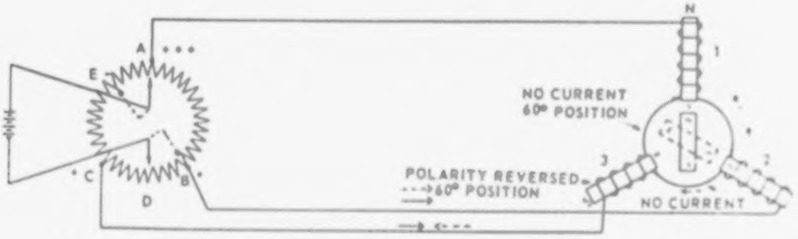
Figure 8-15. Positioning of a bar magnet with three electromagnets.



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0-4b

Figure 8-16. Potentiometer and magnet remote indicator.

that each tap feeds a coil which is in the same relative position about the permanent magnet. That is, tap A on the potentiometer connects to coil 1, which is above the permanent magnet; tap B connects to coil 2 on the right of the permanent magnet; and tap C connects to coil 3 on the left of the permanent magnet.

The difference of potential existing between points AB, BC, and AC on the potentiometer causes currents to flow through the coils. In so doing, these currents produce magnetic fields which interact to produce a resultant field. The permanent magnet, being free to rotate, always tends to align itself with the direction of the resultant field.

The direction of the resultant field depends on the direction and magnitude of the currents in the coils; but these, in turn, depend on the angular position of the sliding contacts on the potentiometer. Let us explain this with a few examples.

Consider first the case where the sliding contacts are aligned vertically. In this case, the voltage between A and B is equal to the voltage between A and C and hence equal currents flow through coils 2 and 3; and the sum of these currents flows through coil 1. If we add vectorially the magnetic fields established about each coil, we find that the axis of the resultant magnetic field is vertical. This is indicated by the fact that the permanent magnet is aligned with coil 1. It is evident that this corresponds to the axis of the sliding contacts of the potentiometer.

Next, let us consider the conditions that exist when the axis of the sliding contacts is rotated 60° counterclockwise. In this case, current will begin at B on the potentiometer, flow through coil 2 and then divide so that half the current flows through coil 1 and the other half flows through coil 3. The magnetic fields now add to produce a resultant field which lines up with coil 2. Note that again the resultant magnetic field takes a position corresponding to the axis of the sliding contacts. (See broken lines.)

In the above examples, we rotated the sliding contacts 60° and saw that the magnet followed the movement of the sliding contacts. We could have moved the sliding contacts in steps of 5°, 10°, or any number of degrees and the result would have been the same. Each time the magnet would have to move to a position corresponding to the position of the sliding contact. Moreover, if the sliding contacts are made to assume a uniform circular motion, the magnet will assume the same motion and remain in synchronism with the rotating potentiometer contacts.

In the previous examples, DC voltages have been applied to the fields. Since synchros operate on AC rather than DC, consider what happens when AC is applied to the electromagnet in figure 8-17. During one complete cycle of the alternating current, the polarity reverses twice. Therefore, the number of times the polarity reverses each second is twice the excitation frequency or 800 times a second when a 400-Hz frequency is applied. Since the magnetic field of the electromagnet follows this alternating current, the bar magnet is attracted in one direction during one-half cycle (view A) and in the other direction during the next half cycle (view B). Because of its inertia, the bar magnet cannot turn rapidly enough to follow the changing magnetic field and may line up with either end toward the coil (view C). This condition also causes weak rotor torque. For these reasons, the iron-bar rotor is not practical for AC applications. Therefore, it is necessary to replace it with an electromagnetic rotor, as illustrated in figure 8-18.

In this figure, both stationary and rotating coils are connected to the same 400-Hz source. During the positive alternation (view A) the polarities are as shown and the top of the rotor is attracted to the bottom of the stationary coil. During the negative alternation (view B) the polarities of both coils reverse, thus keeping the rotor aligned in the same position. In summary, since both magnetic fields change direction at the same time when following the 400-Hz AC supply voltage, the electromagnetic rotor does not change position because it is always in alignment with the stationary magnetic field.

Exercise (491f):

1. How do synchros differ from conventional transformers?

2. Describe the zero-position of a synchro transmitter.

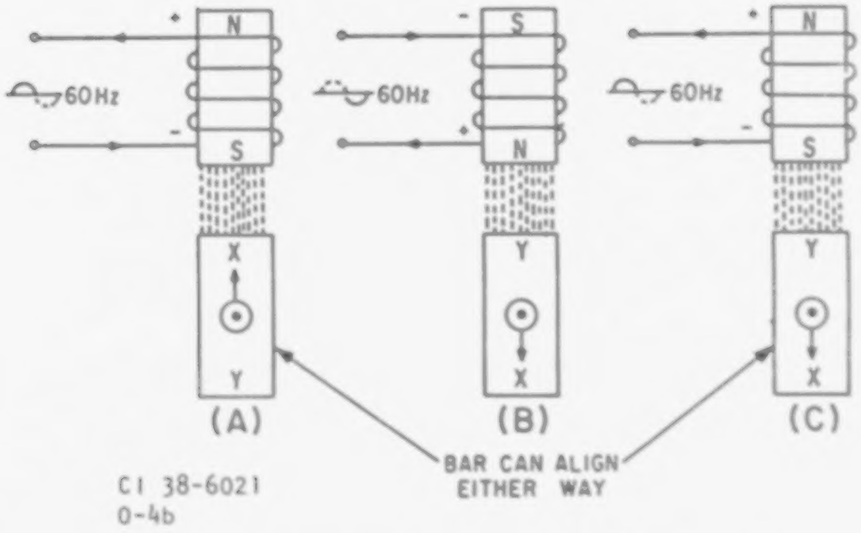

Figure 8-17. Operation of an electromagnet with AC voltage.

491g (517—for CE feedback reference only). Identify operational features of a synchro transmitter.

Synchro Torque Transmitter. The rotor of a synchro transmitter is usually mechanically positioned. The transmitter delivers three output voltages. The synchro transmitter converts the angular position of its rotor (mechanical input) into an electrical output signal. It is helpful in analyzing the operation of a synchro generator (transmitter) to consider the synchro as a transformer in which the rotor winding is the primary and the stator windings are three secondaries. In this case, the voltage induced by the rotor into any one winding depends on (1) the voltage applied to the rotor, (2) the turns ratio between the rotor and stator winding, and (3) the angular orientation of the rotor with respect to the stator. Since the turns ratio and the voltage applied to the rotor are fixed, the only factor that we need consider is the angular position of the rotor with respect to the stator.

When a 115-volt AC excitation voltage is applied through the slip rings to the rotor of a synchro transmitter, such as the one shown in figure 8-19, the resultant current produces an AC magnetic field around the rotor winding.

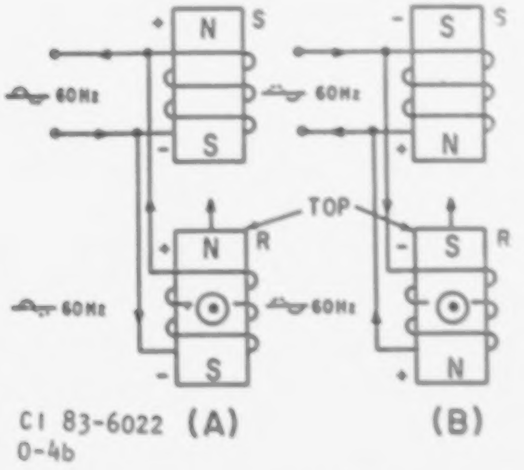

Figure 8-18. Operation of a fixed and a moveable electromagnet with AC voltage.

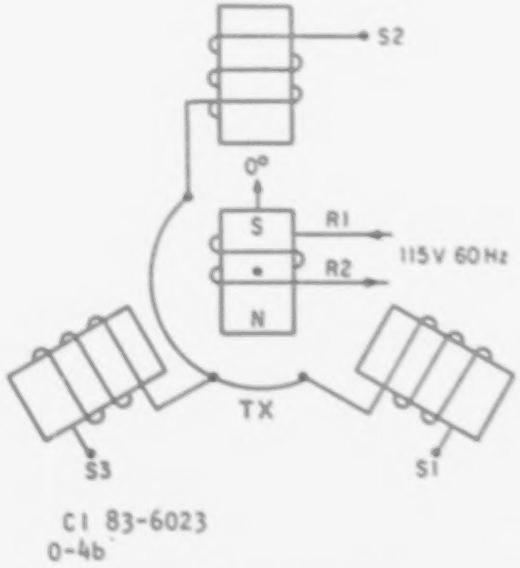

Figure 8-19. Synchro transmitter.

The lines of force cut through the turns of the three stator windings and, by transformer action, induce voltage into the stator coils. The effective voltage induced in any stator coil depends upon the angular position of that coil's axis with respect to the rotor axis. When the maximum effective coil voltage is known, the effective voltage induced into a stator coil at any angular displacement can be determined.

Figure 8-20 is a cross section of a synchro transmitter and shows the effective voltage induced in one stator coil as the rotor is turned to different positions. The turns ratio in synchros may vary widely, depending upon design and application, but there is commonly a 2.2:1 stepdown between the rotor and a single coil. Thus, when 115 volts is applied to the rotor, the highest value of effective voltage that is induced in any one stator coil is 52 volts. This maximum induced voltage occurs each time there is maximum magnetic coupling between the rotor and the stator coil (fig. 8-20 (A), (C), and (E)). The effective voltage induced in the secondary winding is approximately equal to the product of the effective voltage on the primary, the secondary-to-primary turns ratio, and the magnetic coupling between primary and secondary. Therefore, because the primary voltage and the turns ratio are constant, it is commonly said that the secondary voltage varies with the angle between the rotor and stator.

When stator voltages are measured, reference is always made to terminal-to-terminal voltages, (voltage induced between two stator terminals) instead of to a single coil's voltage. This is due to the fact that the voltage induced in one stator winding cannot be measured because the common connection between the stator coils is not physically accessible.

In summary, the synchro transmitter converts the angular position of its rotor into electrical stator signals which are sent through interconnecting wires to other synchro devices.

Exercises (491g):

1. When is the maximum voltage induced into a stator coil?

2. What three factors determine the amplitude of the voltage induced into a stator winding?

491h (518—for CE feedback reference only). Identify physical and operational characteristics of a synchro receiver.

Synchro Torque Receiver (Motor). The operation of a synchro motor may be seen with the aid of figure 8-21. Note that all corresponding terminals are connected together. Let us suppose, temporarily, that the terminals of the motor rotor (indicator or receiver) are open and that only the generator rotor transmitter is energized with 115 volts AC.

Since the corresponding stator coils of the generator and motor are in parallel, the corresponding stator

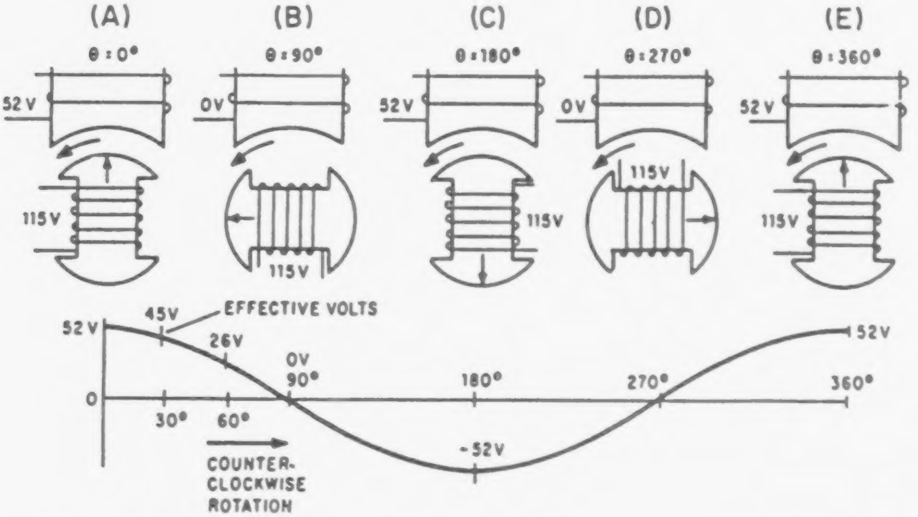

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Figure 8-20. Stator voltage versus rotor position.

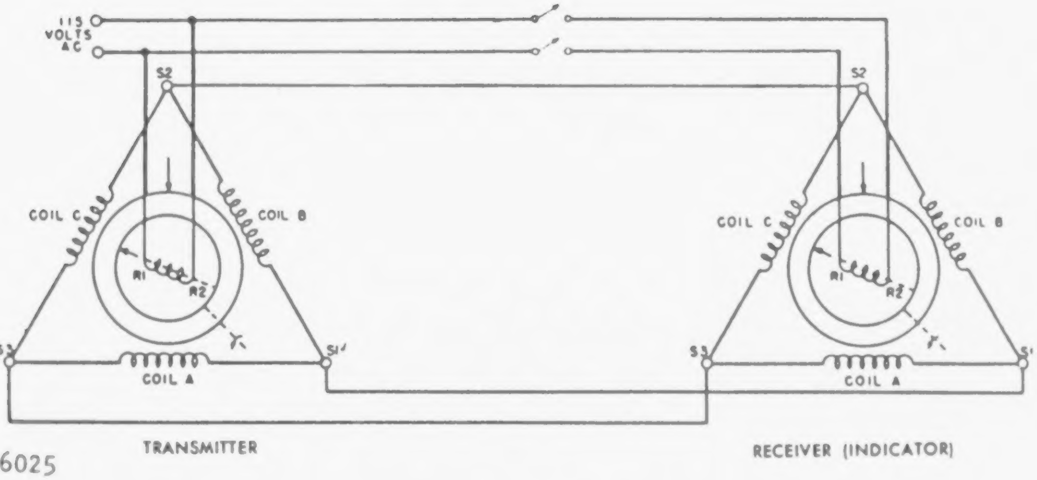

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Figure 8-21. Circuit for explaining operation of synchro motor.

currents will be the same and so will the corresponding magnetic fields. As a consequence, the axis of the resultant magnetic field in the motor will be parallel to the axis of the generator rotor. Hence, if the rotor of the motor is free to move, it will line up with the resultant field in the motor and thereby take a position corresponding to that of the generator rotor.

It is not desirable to operate the motor with its rotor leads open for three reasons: (1) for any position of the generator rotor, there are two stable positions of the motor rotor which are 180° apart; (2) the generator will overheat due to excessive currents flowing through its stator; and (3) the torque developed by the motor is small.

When the motor rotor leads are closed, the rotor becomes polarized so that it will have only one stable position. If the generator and motor are symmetrically connected, the stable position of the motor rotor corresponds precisely to that of the generator rotor. When the two rotors are energized and come into alignment with one another, the stator currents become nearly zero, since the stator voltages of the motor are equal and opposite to those of the generator.

Since the synchro generator and motor are similar machines, the forces acting on each rotor, which tend to bring them into alignment with one another, are the same. That is, if the motor rotor instead of the generator is turned, the generator rotor, if free to move, will follow the movement of the motor rotor.

Usually, however, the generator (transmitter) rotor is geared to a driving mechanism and, therefore, it is the indicator motor rotor which must do the following: Synchro torque receivers, commonly called synchro receivers, are electrically identical to torque transmitters of the same size except for the addition of some form of damping to prevent sudden and erratic movements. In some sizes of 400-Hz synchros, units are designated as torque receivers but may be used as either transmitter or receivers.

Unlike the transmitter, the receiver has an electrical input to its stator and a mechanical output from its rotor. The synchro receiver's function is to convert the electrical data supplied to its stator from the transmitter, back to a mechanical angular position through the movement of its rotor. This function is accomplished when the rotor is connected to the same AC source as the transmitter and assumes a position determined by the interaction of its magnetic field with the magnetic field of the stator. If you recall, this is the same concept discussed earlier under the operation of electromagnets.

Normally, the receiver rotor is unrestrained in movement except for brush and bearing friction. When power is first applied to a system, the transmitter position quickly changes; or if the receiver is switched into the system, the receiver rotor turns to correspond to the position of the transmitter rotor. This sudden motion can cause the rotor to oscillate (swing back and forth) around the synchronous position. If the movement of the rotor is great enough, it may even spin. Some method of preventing oscillations or spinning must be used. Any method that accomplishes this task is termed DAMPING.

There are two types of damping methods—ELECTRICAL and MECHANICAL. In small synchros, the electrical method is more commonly used than the mechanical method. This method uses an additional winding placed in the synchro to retard any oscillation which may occur. In larger units, a mechanical device known as an inertia damper is more effective. Several variations of the inertia damper are in use. One of the more common types consists of a heavy brass flywheel (inertia damper) which is free to rotate around a bushing that is attached to the rotor shaft (fig. 8-22). A tension spring on the bushing rubs against the flywheel so that the bushing and flywheel turn together during normal operation. If the rotor shaft turns or tends to change its speed or direction of rotation suddenly, the inertia of the damper opposes the changing condition.

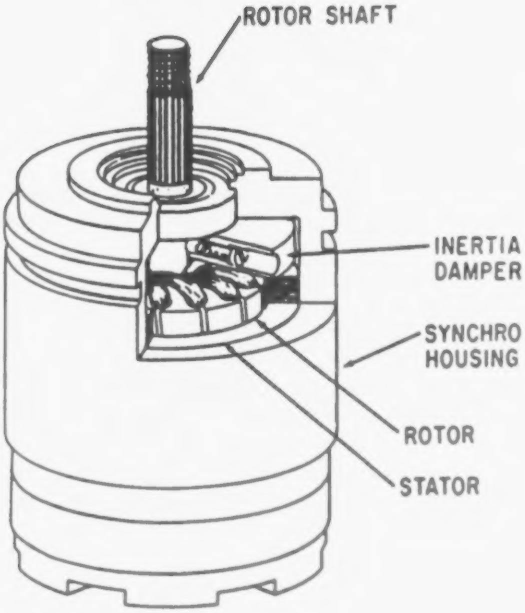
ROTOR SHAFT
INERTIA DAMPER
SYNCHRO HOUSING
ROTOR
STATOR

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Figure 8-22. Cutaway view of torque receiver with inertia damper.

Exercises (491h):

1. What is the physical difference between a synchro transmitter and a synchro receiver?

2. What method is used to prevent oscillations in large synchro units?

Torque Synchro System. A torque transmitter (TX) and a torque receiver (TR) make up a simple torque synchro system. Basically, the electrical construction of synchro transmitters and receivers is similar, but their intended functions are different. The rotor of a synchro transmitter is usually geared to a manual or mechanical input. At the other end of the system, the rotor of the receiver synchronizes itself electrically with the position of the rotor of the transmitter and thus indicates the quantity being transmitted.

491i (519—for CE feedback reference only). State principles of operation of a basic synchro system.

Basic Synchro System Operation. A simple synchro transmission system consisting of a torque transmitter connected to a torque receiver (TX-TR) is illustrated in figure 8-23. As you can see, in this system the rotors are connected in parallel across the AC line. The stators of both synchros have their leads connected S1 to S1, S2 to S2, and S3 to S3, so that the voltage in each of the transmitter stator coils opposes the voltage in the corresponding coils

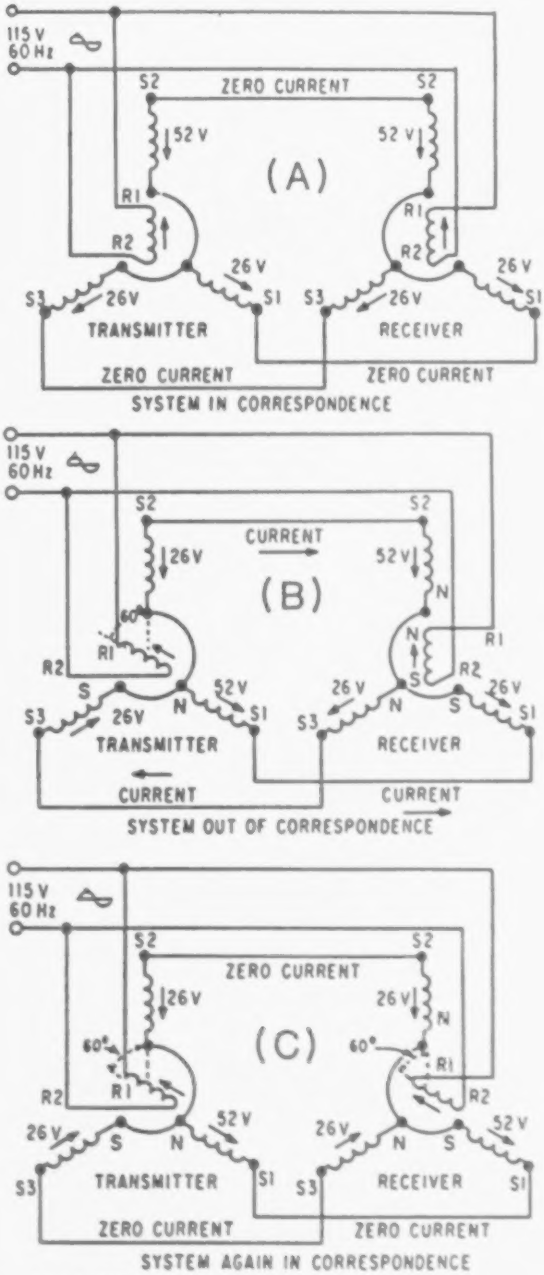
115 V
60 Hz
S2
ZERO CURRENT
S2
52 V
52 V
(A)
R1
R2
R1
R2
26 V
26 V
S3
26V
S1
S3
26V
S1
TRANSMITTER
RECEIVER
ZERO CURRENT
ZERO CURRENT
SYSTEM IN CORRESPONDENCE
115 V
60 Hz
S2
S2
CURRENT
26V
52 V
(B)
N
60°
R1
R1
N
R2
S
R2
S
52 V
26 V
26 V
N
N
S
S3
26V
S1
S3
S1
TRANSMITTER
RECEIVER
CURRENT
CURRENT
SYSTEM OUT OF CORRESPONDENCE
115 V
60 Hz
S2
S2
ZERO CURRENT
26V
26 V
N
(C)
60°
60°
R1
R1
R2
R2
52 V
26 V
26 V
52 V
S
N
N
S
S3
TRANSMITTER
S1
S3
RECEIVER
S1
ZERO CURRENT
ZERO CURRENT
SYSTEM AGAIN IN CORRESPONDENCE

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Figure 8-23. A simple synchro transmission system.

of the receiver. The voltage directions are indicated by arrows for the instant of time shown by the dot on the AC line voltage.

When both transmitter and receiver rotors in a synchro system are on zero or displaced from zero by the same angle, a condition known as CORRESPONDENCE exists. In figure 8-23(A), the transmitter and receiver are shown in correspondence. In this condition, the rotor of the TR induces voltages in its stator coils (S2 = 52V, S1, and S3 = 26V) which are equal and in opposition to the voltages induced into the TX stator coils (S2 = 52V, and S3 = 26V). This causes the voltages to cancel and reduces the stator currents to zero. With zero current through the coils, the receiver torque is zero and the system remains in correspondence.

The angle through which a transmitter rotor is mechanically rotated is called a SIGNAL. In figure 8-23(B) the signal is 60°. Now, consider what happens to the two synchros in correspondence when this signal is generated.

When the transmitter rotor is turned, the rotor field follows and the magnetic coupling between the rotor and stator windings changes. This results in the transmitter S2 coil voltage decreasing to 26 volts, the S3 coil voltage reversing direction, and S1 coil voltage increasing to 52 volts. This imbalance in voltages, between the transmitter and receiver, causes current to flow in the stator coils in the direction of the stronger voltages. The current flow in the receiver produces a resultant magnetic field in the receiver stator in the same direction as the rotor field in the transmitter. A force (torque) is now exerted on the receiver rotor by the interaction between its resultant stator field and the magnetic field around its rotor. This force causes the rotor to turn through the same angle as the rotor of the transmitter. As the receiver approaches correspondence, the stator voltages of the transmitter and receiver approach equality. This action decreases the stator currents and produces a decreasing torque on the receiver. When the receiver and the transmitter are again in correspondence, as shown in figure 8-23(C), the stator voltages between the two synchros are equal and in opposition (S1 = 52V, S2, and S3 = 26V), the rotor torque is zero, and the rotors are displaced from zero by the same angle (60°). This sequence of events causes the transmitter and receiver to stay in correspondence.

In the system just explained, the receiver reproduced the signal from the transmitter. As you can see, a synchro system such as this could provide a continuous, accurate, visual reproduction of important information to remote locations.

Exercises (491i):

1. What two components make up a simple synchro transmission system?

2. What leads in a simple synchro system are connected to the AC power line?

3. What is the relationship between the transmitter and receiver stator voltages when their rotors are in correspondence?

4. What is the name given to the angle through which a transmitter's rotor is mechanically rotated?

491j (520—for CE feedback reference only). State how a desired direction of receiver rotation is achieved.

Receiver Rotation. When the teeth of two mechanical gears are meshed and a turning force is applied, the gears turn in opposite directions. If a third gear is added, it turns in the same direction as the first. This is an important fact, because the output of a synchro receiver is often connected through a train of mechanical gears to the device which it operates. Whether or not force is applied to the device in the same direction as that in which the receiver rotor turns depends on whether the number of gears in the train is odd or even. The important thing, of course, is to move the dial or other device in the proper direction. Even when there are no gears involved, the receiver rotor may turn in the direction opposite to that which you desire. To correct this problem, some method must be used to reverse receiver rotation. In the transmitter-receiver system, this is accomplished by reversing the S1 and S3 connections so that S1 of the transmitter is connected to S3 of the receiver and vice versa (fig. 8-24).

Even when the S1 and S3 connections are reversed, the system at 0° acts the same as the basic synchro system previously described at 0°. This is because the voltages induced in the S1 and S3 stator windings are still equal and oppose each other. This causes a canceling effect, which results in zero stator current and no torque. Without the torque required to move the receiver rotor, the system remains in correspondence and the reversing of the stator conection has no noticeable effect on the system at 0°.

Suppose the transmitter rotor is turned counterclockwise 60°, as shown in figure 8-24(A). The TX rotor is now aligned with S1. This results in maximum magnetic coupling between the TX rotor and the S1 winding. As a result of this coupling, maximum voltage is induced in S1. Because S1 is connected to S3 of the TR, a voltage imbalance occurs between them. As a result of this voltage imbalance, maximum current flows through the S3 winding of the TR, causing it to have the strongest magnetic field. Because the other two fields around S2 and S1 decrease proportionately, the S3 field has the greatest effect on the resultant TR stator field. The strong S3 stator field forces the rotor to turn 60° clockwise into alignment with itself, as shown in figure 8-24(B). At this point, the

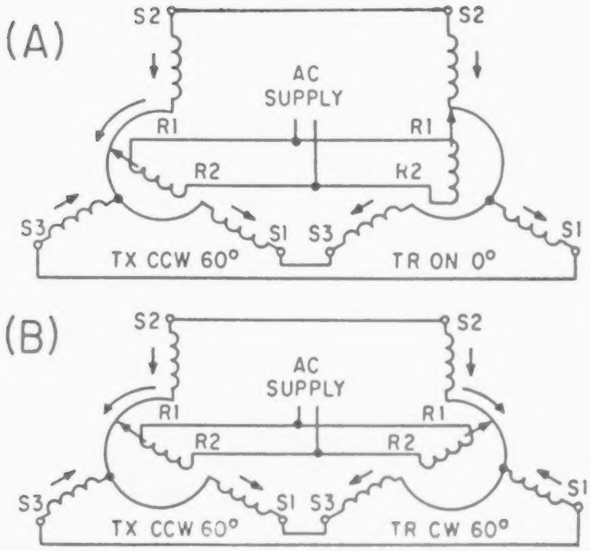


Figure 8-24. Effect of reversing S1 and S3 connections between the transmitter and receiver.

rotor of the TR induces canceling voltages in its own stator coils and causes the rotor to stop. The system is now in correspondence. Notice that by reversing S1 and S3, both synchro rotors turn the same amount but in OPPOSITE DIRECTIONS.

It is important to emphasize that the only stator leads ever interchanged, for the purpose of reversing receiver rotation, are S1 and S3. S2 cannot be reversed with any other lead since it represents the electrical zero position of the synchro. As you know, the stator leads in a synchro are 120° apart, therefore, any change in the S2 lead causes a 120° error in the synchro system and also reverses the direction of rotation.

In new or modified synchro systems, a common problem is the accidental reversal of the R1 and R2 leads on either the transmitter or receiver. This causes a 180° error between the two synchros, but the direction of rotation remains the same.

Effect of Changing Synchro Connections. The effect of changing synchro connections is shown in figure 8-25.

When the synchro connections are symmetrical, the motor rotor assumes very nearly the same angle as the generator rotor and follows it in its rotation.

If the rotor connections are reversed as in figure 8-25(B), the motor rotor will follow the generator in its direction of rotation but will have a constant displacement of 180°. This is indicated by the opposite direction of the arrows within the rotor of each machine.

If a cycle shift is made in the stator connections, as shown in figure 8-25(C), the motor will follow the generator in its direction of rotation but will have a constant displacement with respect to it of 120°.

If it is desired that the generator turn with the motor, but in the opposite direction, the usual practice is to reverse the connections to S1 and S3 leaving S2 unchanged. With this arrangement, the two rotors turn in opposite directions but reach electrical zero at the same instant. Interchanging any other two stator connections will cause a lead or lag of 120°. (See fig. 8-25(C) and (D).)

A generator may be connected to more than one motor. For example, on an aircraft, a compass can be wired to a number of motors or compass repeaters at various locations onboard. Figure 8-26 shows a generator connected to three motors. When a generator is connected to more than one motor, it must be larger than the motors in order to have the required power-handling capability. It must be remembered in this type of operation that all the motors should be free to turn. Should any one of the motors jam, the accuracy of the other motors will be impaired. The reason for this is that the jammed motor will act as a generator.

Exercises (491j):

1. Which leads are reversed when it is necessary to reverse the rotor's direction of rotation?

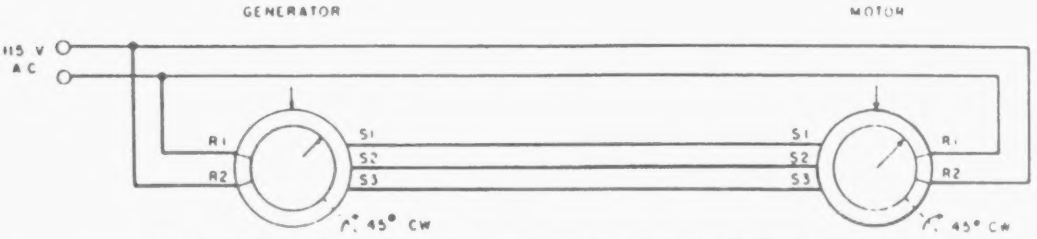
2. What configuration would cause the transmitter shaft to be at 0° when the receiver shaft is at 180°?

491k (521—for CE feedback reference only). Differentiate between control synchros and torque synchros.

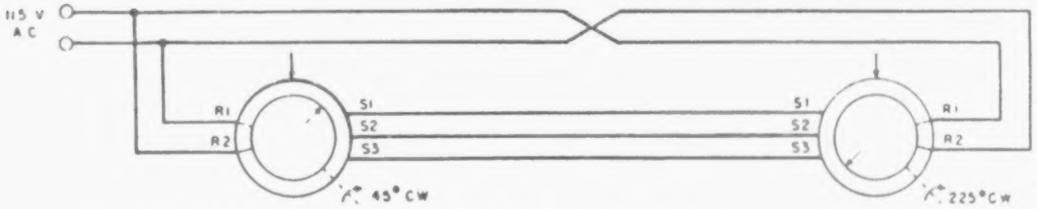
Control Synchro Systems. It should be clear to you from our discussion of torque synchro systems that since they produce a relatively small mechanical output, they are suitable only for very light loads. Even when the torque system is moderately loaded, it is never entirely accurate because the receiver rotor requires a slight amount of torque to overcome its static friction.

When large amounts of power and a higher degree of accuracy are required, as in the movement of heavy radar antennas and control surfaces, then torque synchro systems give way to the use of CONTROL SYNCHROS. Control synchros by themselves cannot move heavy loads. However, they are used to "control" servo systems which, in turn, do the actual movement. Servo systems are covered in depth later in the course, along with synchro differentials.

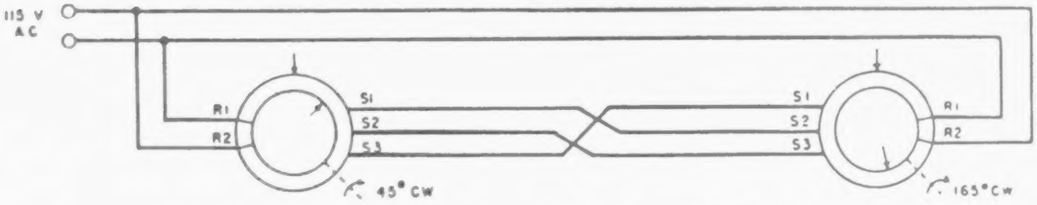
There are three types of control synchros: the CONTROL TRANSMITTER (CX), the CONTROL TRANSFORMER (CT), and the CONTROL DIFFERENTIAL


GENERATOR
MOTOR
115 V AC
R1
R2
S1
S2
S3
45° CW
45° CW

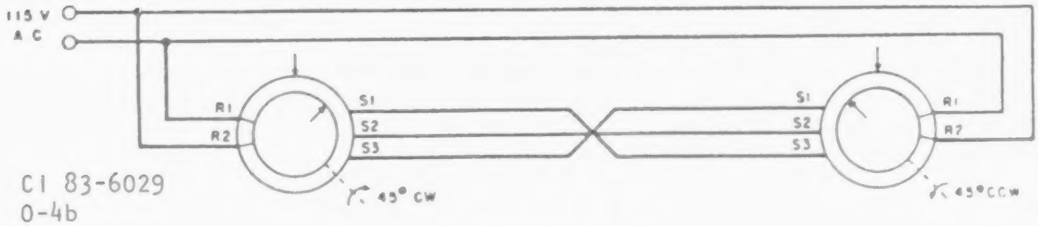
(A) SYMMETRICAL CONNECTION BETWEEN SYNCHRO MOTOR AND GENERATOR


115 V AC
R1
R2
S1
S2
S3
45° CW
225° CW

(B) EFFECT OF REVERSING ROTOR CONNECTIONS

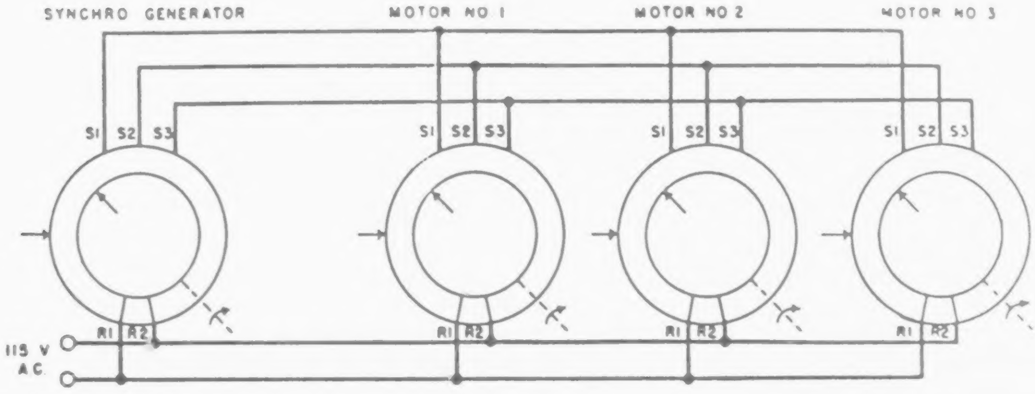

115 V AC
R1
R2
S1
S2
S3
45° CW
165° CW

(C) EFFECT OF A CYCLIC SHIFT OF STATOR CONNECTIONS


115 V AC
R1
R2
S1
S2
S3
45° CW
45° CCW

CI 83-6029
0-4b

Figure 8-25. Effect of changing connections between synchros.


SYNCHRO GENERATOR
MOTOR NO 1
MOTOR NO 2
MOTOR NO 3
S1 S2 S3
R1 R2
115 V AC

CI 83-6030
0-4b

Figure 8-26. One synchro generator controlling three motors.

TRANSMITTER (CDX). The control transmitter (CX) and the control differential transmitter (CDX) are identical to the TX and the TDX except for higher impedance windings. This change in impedance is necessary, since control systems require a voltage output while torque systems require a high current to produce the driving force needed to position an indicator. Therefore, since the theory and operation of the TX and the TDX were discussed earlier, their counterparts, the CX and CDX, are not covered. However, the third control synchro, the CT, is covered in depth during this discussion.

Control Transformers. A control transformer is just what its name implies—a control synchro device accurately governing some type of power-amplifying device that is used for moving heavy equipment. Figure 8-27 shows a phantom view of a typical CT and its schematic symbols.

The CT has the capability of comparing two signals, the electrical signal applied to its stator and the mechanical signal applied to its rotor. The CT output is a difference signal that, in turn, controls a power-amplifying device and thus the movement of heavy equipment. How this control is accomplished is covered in the following paragraphs.

The unit construction and physical characteristics of a control transformer are similar to those of a control transmitter or torque receiver, except that there is no damper and the rotor is a drum or wound rotor rather than a salient-pole rotor.

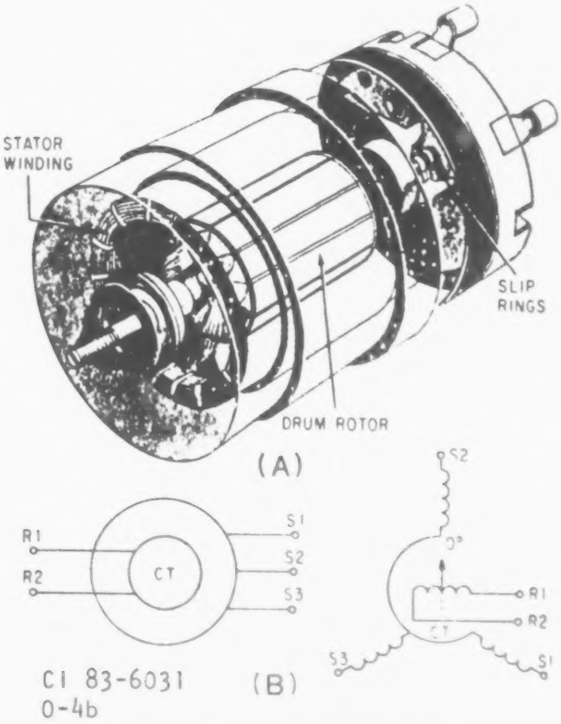


Figure 8-27. (A) Phantom view of a typical CT; (B) CT schematic symbol.

An interesting point about the rotor is that it is never connected to an AC supply and, therefore, induces no voltages in the stator coils. As a result, the CT stator currents are determined solely by the voltages applied to the high-impedance stator windings. The rotor itself is wound so that its position has very little effect on the stator currents. Also, there is never any appreciable current flowing in the rotor because its output voltage is always applied to a high-impedance load. As a result, the CT rotor does not try to follow the magnetic field of its stator and must be turned by some external force.

The stator windings of the CT are considered to be the primary windings and the rotor windings, the secondary windings. The output, which is taken off the R1 and R2 rotor leads, is the voltage induced in the rotor windings. The phase and amplitude of the output voltage depend on the angular position of the rotor with respect to the magnetic field of the stator.

Exercises (491k):

1. What type of synchro is used in systems requiring large amounts of power and a high degree of accuracy?

2. What are the three types of control synchros?

3. How does the CX differ from the TX?

4. What three things prevent a CT rotor from turning when voltages are applied to its stator windings?

491l (522—for CE feedback reference only). Identify operational features of control synchro systems.

Control Synchro System Operation. A control synchro system consisting of a control transmitter and a control transformer is illustrated in figure 8-28. The stator windings of the CX are connected to the stator windings of the CT and both synchros are shown on 0°. Notice, that at 0°, the CT rotor is perpendicular to its S2 winding. This is contrary to what we have learned so far about synchros, but it is just another peculiarity of the CT. When the rotor of the CX is on 0°, the rotor's magnetic field points straight up as shown (the black arrow). The voltages induced in the CX stator windings, as a result of this field,

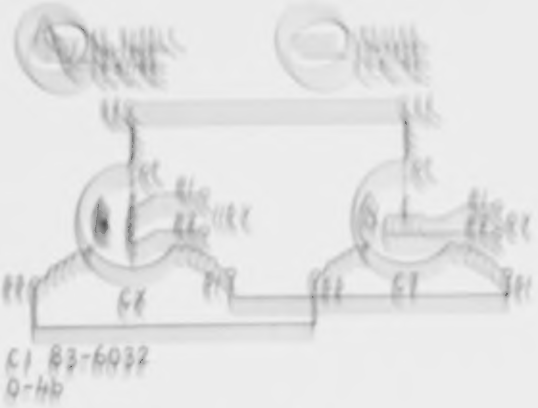


Figure 8-28. CX-CT system operation with rotors in correspondence.

are impressed on the CT stator windings through the three leads connecting the S1, S2, and S3 terminals. Exciting currents proportional to these voltages flow in the CT stator windings and establish a magnetic field in the CT in the same direction (white arrow) as the magnetic field (black arrow) in the CX. Observe that the rotor of the CT is perpendicular to the stator magnetic field; and, therefore, the induced voltage in the rotor is zero, as indicated by the straight line on the oscilloscope presentation.

When the CT rotor is rotated 90°, as shown in figure 8-29, the rotor is parallel to the resultant stator field. Maximum magnetic coupling occurs between the rotor and stator fields at this point. [illegible] magnetic field induces a voltage across the rotor which is proportional to the amount of rotation and in phase with [illegible] This phase relationship between the AC supply voltage and the CT output voltage becomes more apparent in figure 8-30.

When the rotor of the CX in figure 8-30(A) is turned 60° clockwise, the magnetic field in the CX (black arrow) and the magnetic field in the CT (white arrow) also rotate 60° clockwise. This action induces a voltage in the CT rotor which is in phase with AC supply, as indicated by the oscilloscope presentation. If the rotor of the CX in figure 8-30(B) is turned 60° in a counterclockwise direction from its 0° position, the magnetic field (white arrow) in the CT also rotates counterclockwise through the same number of degrees as the CX. Since the magnetic field in the stator of the CT cuts through the rotor in the opposite direction, the induced voltage in the rotor is now out of phase with the AC supply to the CX, as shown in the oscilloscope presentation.

At times it is necessary, because the CT is used to control servosystems, to have the CT output reduced to zero volts to prevent any further movement of a load. To accomplish this, it is necessary to turn the rotor of the CT through the same number of degrees and in the same direction as the rotor of the CX. This places the CT rotor perpendicular to its own stator field and reduces its output to zero volts as illustrated in figure 8-30(C).

The CT output voltage discussed throughout this [illegible] used in moving the load in a typical servosystem.

Now that we have covered the basic operation of the control synchro system, let us see how this system works in conjunction with a servosystem to move heavy equipment. Figure 8-31 shows a block diagram of a typical servosystem that uses a control synchro system. *Assume that the shaft of the CX in this system is turned by some mechanical input. This causes an error signal to be generated by the CT because the CX and the CT rotors are now out of correspondence. The error signal is amplified by the servoamplifier and applied to the servomotor. The servomotor turns the load and, through a mechanical linkage called RESPONSE, also turns the rotor of the CT. The servo motor turns the rotor of the CT so that it is once again in correspondence with the rotor of the CX, the error signal drops to zero volts, and the system comes to a stop.*

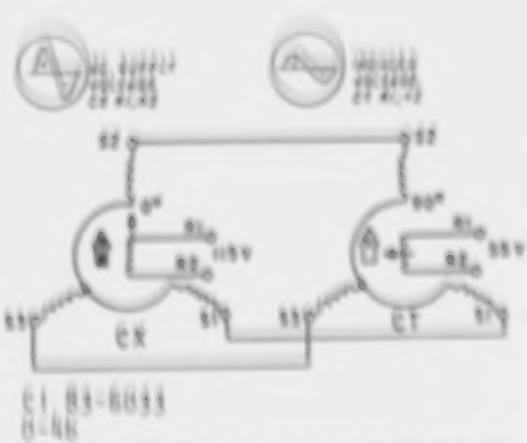


Figure 8-29. CX-CT system operation with the CX rotor at 0° and the CT rotor at 90°.

Exercises ([illegible]):

1. When a CT is on electrical zero, what is the relationship between its rotor and the S2 winding?

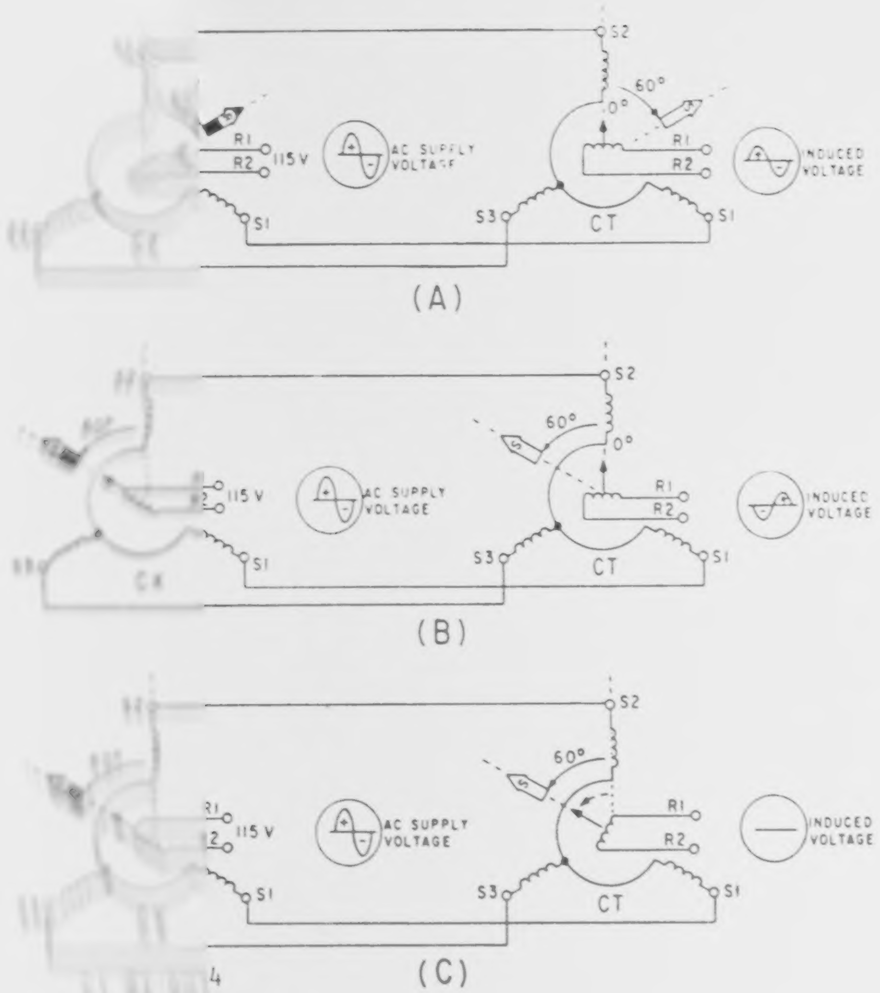
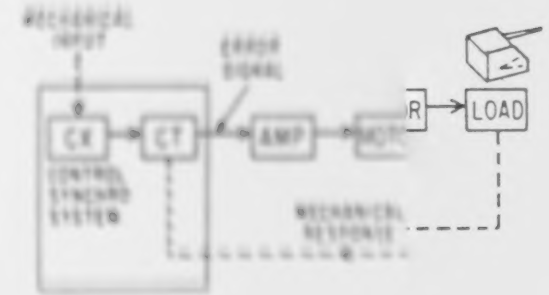

S2
60°
0°
R1
R2
115 V
AC SUPPLY VOLTAGE
INDUCED VOLTAGE
S1
S3
CT
CX
(A)
(B)
(C)

Figure 8-30. Control synchro operation.


MECHANICAL INPUT
ERROR SIGNAL
CX
CT
AMP
MOTOR
LOAD
CONTROL SYNCHRO SYSTEM
MECHANICAL RESPONSE

rol synchro system.

2. What are the amplitude and phase of the voltage induced into the rotor of a CT when the CX is turned 90° clockwise while the CT remains on electrical zero?

3. What is the name given to the electrical output of a CT?

4. In a control synchro system, when is the output of the CT reduced to zero?

491m (523—for CE feedback reference only). State methods used to zero synchros.

Zeroing Synchros. If synchros are to work properly in a system, it is essential that they be correctly connected and aligned with respect to each other and to the other devices with which they are used. The reference point for alignment of all synchro units is ELECTRICAL ZERO. The mechanical reference point for the units connected to the synchros depends upon the particular application of the synchro system. Whatever the application, the electrical and mechanical reference points must be aligned with each other. The mechanical position is usually set first and then the synchro device is aligned to the electrical zero.

There are various methods of zeroing synchros. Some of the more common zeroing methods are the voltmeter, the electrical-lock, and the synchro-tester methods. The method used depends upon the facilities and tools available and how the synchros are connected in the system. Also, the method for zeroing a unit whose rotor or stator is not free to turn may differ from the procedures for zeroing a similar unit whose rotor or stator is free to turn.

Voltmeter method. The most accurate method of zeroing a synchro is the AC voltmeter method. The procedure and the test circuit configuration for this method vary somewhat, depending upon which type of synchro is to be zeroed. Transmitters and receivers, differentials, and control transformers each require different test circuit configurations.

Regardless of the synchro to be zeroed, there are two major steps in each procedure. The first step is the coarse or approximate setting. The second step is the fine setting. The coarse setting ensures that the device is zeroed on the 0° position rather than the 180° position. Many synchro units are marked in such a manner that the coarse setting may be approximated physically by aligning two marks on the synchro. On standard synchros this setting is indicated by an arrow stamped on the frame and a line marked on the shaft, as shown in figure 8-32. The fine setting is where the synchro is precisely set on 0°.

For the AC voltmeter method to be as accurate as possible, an electronic or precision voltmeter having a 0- to 250-volt and a 0- to 5-volt range should be used. On the low scale this meter should also be able to measure voltages as low as 0.1 volt.

Zeroing Transmitters and Receivers (Voltmeter Method). Since the TX, CX, and TR are functionally and physically similar, they can be zeroed in the same manner. For the TX and CX to be properly zeroed, electrical zero voltages (S2 - 52V, S1 and S3 - 26V) must exist across the stator winding when the rotor of the transmitter is set to 0° or its mechanical reference position. The synchro receiver (TR) is properly zeroed when the device it actuates assumes its zero or mechanical reference position while electrical zero voltages (S2 - 52V, S1 and S3 - 26V) exist across its stator windings. The following is a step-by-step procedure used to zero the TX, CX, and TR.

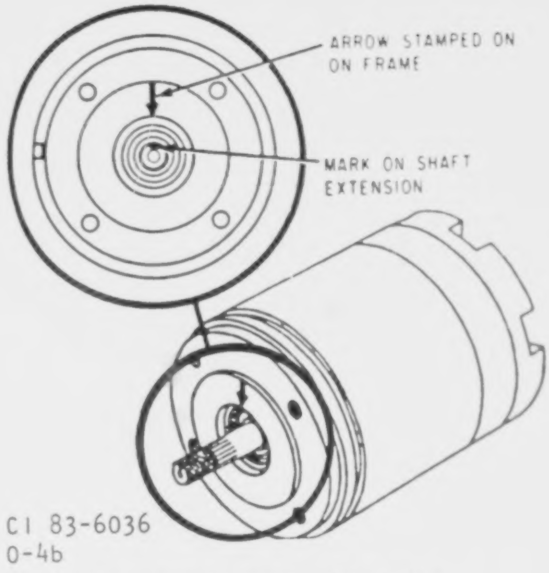


Figure 8-32. Coarse electrical zero marking.

(1) Carefully set the unit (antenna, bourdon tube, control surface, etc.), whose position the CX or TX transmits, accurately on 0° or on its reference position. In the case of the TR, deenergize the circuit and disconnect the stator leads prior to setting its rotor on zero or to its reference position. The rotor may need to be secured in this position; taping the dial to the frame is usually sufficient.

(2) Deenergize the synchro circuit and disconnect the stator leads.

NOTE: Many synchro systems are energized by individual switches. Therefore, be sure that the synchro power is off before working on the connections.

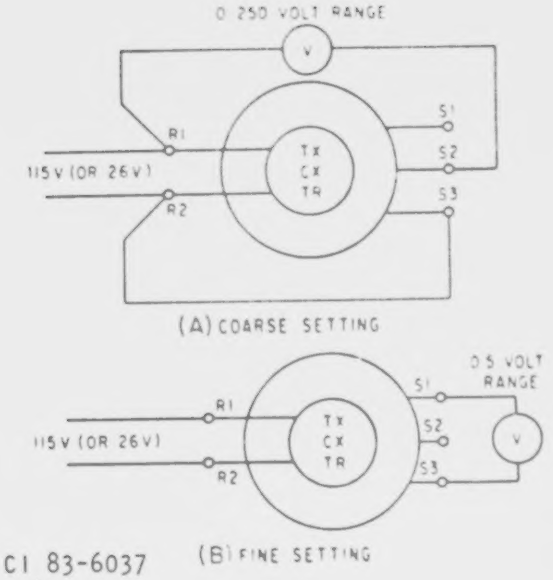
Set the voltmeter to its 0- to 250-volt scale and connect it into the circuit as shown in figure 8-33(A).

(3) Energize the synchro circuit and turn the stator until the meter reads about 37 volts (15 volts for a 26-volt synchro). Should the voltmeter read approximately 193 volts (115 volts + 78 volts = 193 volts), the rotor is at 180° and must be turned through a half revolution to bring it back to 0°. If the 37 volts (15 volts) cannot be obtained, use the lowest reading taken with the meter. This is the coarse setting and places the synchro approximately on electrical zero.

(4) Deenergize the synchro circuit and connect the meter as shown in figure 8-33(B). Start with a high scale on the meter and work down to the 0- to 5-volt scale to protect the meter movement.

(5) Reenergize the synchro circuit and adjust the stator for a zero or minimum voltage reading. This is the fine electrical zero position of the synchro.

Once the TX and a TR have been reconnected in a system after zeroing, a simple check can be performed on the system to see if they are accurately on electrical zero. First, place the transmitter on 0°. When the system



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0-4b

Figure 8-33. Zeroing a transmitter or receiver by the voltmeter method.

reaches the point of correspondence, then the induced voltages in the S1 and S3 stator windings of both synchros should be equal. Since the terminals of S1 and S3 are at equal potential, a jumper between these terminals at the TR should not affect the circuit. If, however, the TR rotor moves when a jumper is connected, there is a slight voltage difference between S1 and S3, which indicates that the transmitter is not on electrical zero. If this is the case, the transmitter must be rechecked for electrical zero.

Exercises (491m):

1. What is the reference point for alignment of all synchro units?

2. What is the most accurate method of zeroing a synchro?

3. What is the purpose of the coarse setting of a synchro?

491m (524—for CE feedback reference only). Theoretically troubleshoot synchro circuits.

Troubleshooting Synchro Systems. One of your duties is to keep the synchro systems in your equipment in good working order. Therefore, it is essential that you become familiar with the details of synchro maintenance and repair.

First, let us consider some of the more common problem areas that you should avoid when working with synchros. As with any piece of electrical or electronic equipment, if it works, let it alone. Do not attempt to zero a synchro system which is already accurately zeroed just because you want to practice. More often than not, the system will end up more out of alignment than it was before you attempted to rezero it. Do not attempt to take a synchro apart, even if it is defective. A synchro is a piece of precision equipment which requires special equipment and techniques for its disassembly. This should be done only by qualified technicians in authorized repair shops. A synchro, unlike an electric motor, does not require periodic lubrication. Therefore, never attempt to lubricate a synchro. Synchros also require careful handling. Therefore, you should never force a synchro into place, never use pliers on the threaded shaft, and never force a gear or dial on the shaft. Finally, never connect other equipment which is not related to the synchro system to the primary excitation bus. This will cause the system to show all the symptoms of a shorted rotor when the equipment is turned on, but the system will check out good when it is off.

Trouble in a synchro system which has been in operation for some time is usually one of two types. First, the interconnecting synchro wiring often passes through a number of switches; as these points open, shorts or grounds may occur. You will be expected to trace down these troubles with an ohmmeter. An open can be found easily by checking for continuity between two points. Similarly, a ground can be found by checking the resistance between the suspected point and ground. A reading of zero ohms means that the point in question is grounded. Secondly, the synchro itself may become defective due to opens and shorts in the windings, bad bearings, worn slip rings, or dirty brushes. You can do nothing about these defects except replace the synchro.

Troubles in either new and modified synchro systems are most often due to (1) improper wiring and (2) misalignment due to synchros not being zeroed. It is your responsibility to find and correct these troubles. Improper wiring can be checked with an ohmmeter by making a point-to-point continuity and resistance check. Misalignment of a synchro system can be corrected by rezeroing the entire system.

Symptoms and Causes. To help the technician further isolate synchro problems, many manufacturers furnish tables of trouble symptoms and probable causes with their equipment. These tables are a valuable aid in isolating trouble areas quickly. Tables 8-3 through 8-8 summarize, for a sample TX-TR system, some typical trouble symptoms and their probable causes. Keep in mind that if two or more receivers are connected to one transmitter, similar symptoms occur. However, if all the receivers act up, the trouble is usually in the transmitter or main bus. If the trouble appears in one receiver only, check that

TABLE 8-3
GENERAL SYMPTOMS

Preliminary Actions: Be sure TR is not jammed physically. Turn TX slowly in one direction and observe TR.

Symptoms	Trouble
Units hum at all TX settings. One unit overheats. TR follows smoothly but reads wrong.	Rotor circuit open or shorted. See table 8-2.
Units hum at all except two opposite TX settings. Both units overheat. TR stays on one reading half the time, then swings abruptly to the opposite one. TR may oscillate or spin.	Stator circuit shorted. See table 8-3.
Units hum on two opposite TX settings. Both units get warm. TR turns smoothly in one direction, then reverses.	Stator circuit open. See table 8-5.
TR reads wrong or turns backwards, follows TX smoothly.	Unit interconnections wrong. Unit not zeroed. See tables 8-5 and 8-8.

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0-4b

TABLE 8-4
OPEN OR SHORTED ROTOR

Preliminary Action: Set TX at 0° and turn rotor smoothly counterclockwise.

Symptoms	Trouble
TR turns counterclockwise from 0° to 180° in a jerky or erratic manner, and gets hot.	TX rotor open.
TR turns counterclockwise from 0° or 180° in a jerky or erratic manner. TX gets hot.	TR rotor open.
TR turns counterclockwise from 90° or 270°, torque is about normal, motor gets hot, and TX fuses blow.	TR rotor shorted.
TR turns counterclockwise from 90° or 270°, torque is about normal, TX gets hot, and TR fuses blow.	TR rotor shorted.

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0-4b

TABLE 8-5
SHORTED STATOR

Symptoms		Trouble
Setting or Conditions	Indication	
When TX is on 120° or 300° but When TX is between 340° and 80°, or between 160° and 260°	TR reads correctly. Units get hot and hum, and TR stays on 120° or 300°, or may swing suddenly from one point to the other	Stator circuit shorted from S1 to S2.
When TX is on 60° or 240° but When TX is between 280° and 20°, or between 100° and 200°	TR reads correctly. Units get hot and hum, and TR stays on 60° or 240°, or may swing suddenly from one point to the other.	Stator circuit shorted from S2 to S3. Stator circuit shorted from S2 to S3.
When TX is on 0° or 180° but When TX is between 40° and 140°, or between 220° and 320°	TR reads correctly. Units get hot and hum, and TR stays on 0° or 180°, or may swing suddenly from one point to the other.	Stator circuit shorted from S1 to S3. Stator circuit shorted from S1 to S3.
	Both units get very hot and hum, TR does not follow at all or spins.	All three stator leads shorted together.

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receiver and its connections. The angles shown in these tables do not apply to systems using differentials or to systems whose units are incorrectly zeroed.

In a control system, the trouble may be slightly more difficult to isolate. However, the existence of trouble is readily indicated when the system does not properly respond to an input order. For control systems, it is easier to locate the trouble by using a synchro tester or by checking the operating voltages.

Voltage Testing. Another good way to isolate the trouble in an operating synchro system is to use known operating voltages as references for faulty operation. Since the proper operation of a system is indicated by specific rotor and stator voltages, an AC voltmeter can be used to locate the trouble. When an AC voltmeter is connected between any two stator leads, the voltage should vary from 0 to 90 volts (0 to 11.8 volts for 26-volt systems) as the transmitter rotates. The zero and maximum voltage values should occur at the headings shown in table 8-2.

Exercises (491n):

1. In which of the circuits shown in figure 8-34 will the signal be reversed?

2. What effect does the circuit configuration "C" of figure 8-34 have on the signal?

TABLE 8-6
OPEN STATOR

Symptoms		Trouble
Setting or Conditions	Indications	
When TX is 150° or 330° and When TX is held on 0°	TR reverses or stalls. TR moves between 300° and 0° in a jerky or erratic manner.	S1 stator circuit open.
When TX is on 90° or 270° and When TX is held on 0°	TR reverses or stalls. TR moves to 0° or 180°, with fairly normal torque.	S2 stator circuit open.
When TX is on 30° or 210° and When TX is held on 0°	TR reverses or stalls. TR moves between 0° and 60° in a jerky or erratic manner.	S3 stator circuit open.
When TX is set at 0°, and then moved smoothly counterclockwise	TR does not follow. No hum or overheating.	Two or three stator leads open or both rotor circuits open.

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0-4b

TABLE 8-7
WRONG STATOR CONNECTIONS, ROTOR WIRING CORRECT

Setting or Conditions	Indication	Trouble
TX set to 0° and rotor turned smoothly counterclockwise	TR indication is wrong, turns clockwise from 240°.	S1 and S2 stator connections are reversed.
	TR indication is wrong, turns clockwise from 120°.	S2 and S3 stator connections are reversed.
	TR indication is wrong, turns clockwise from 0°.	S1 and S3 stator connections are reversed.
	TR indication is wrong, turns counterclockwise from 120°.	S1 is connected to S2, S2 is connected to S3, and S3 is connected to S1.
	TR indication is wrong, turns counterclockwise from 240°.	S1 is connected to S3, S2 is connected to S1, and S3 is connected to S2.

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0-4b

TABLE 8-8
WRONG STATOR AND/OR REVERSED ROTOR CONNECTIONS

Setting or Conditions	Indication	Trouble
TX is set to 0° and rotor turned smoothly counterclockwise	TR indication is wrong, turns counterclockwise from 180°.	Stator connections are correct, but rotor connections are reversed.
	TR indication is wrong, turns clockwise from 60°.	Stator connections S1 and S2 are reversed, and rotor connections are reversed.
	TR indication is wrong, turns clockwise from 300°.	Stator connections S2 and S3 are reversed, and rotor connections are reversed.
	TR indication is wrong, turns clockwise from 180°.	Stator connections S1 and S3 are reversed, and rotor connections are reversed.
	TR indication is wrong, turns counterclockwise from 300°.	S1 is connected to S2, S2 is connected to S3, S3 is connected to S1, and rotor connections are reversed.
	TR indication is wrong, turns counterclockwise from 60°.	S1 is connected to S3, S2 is connected to S1, S3 is connected to S2, and rotor connections are reversed.

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0-4b

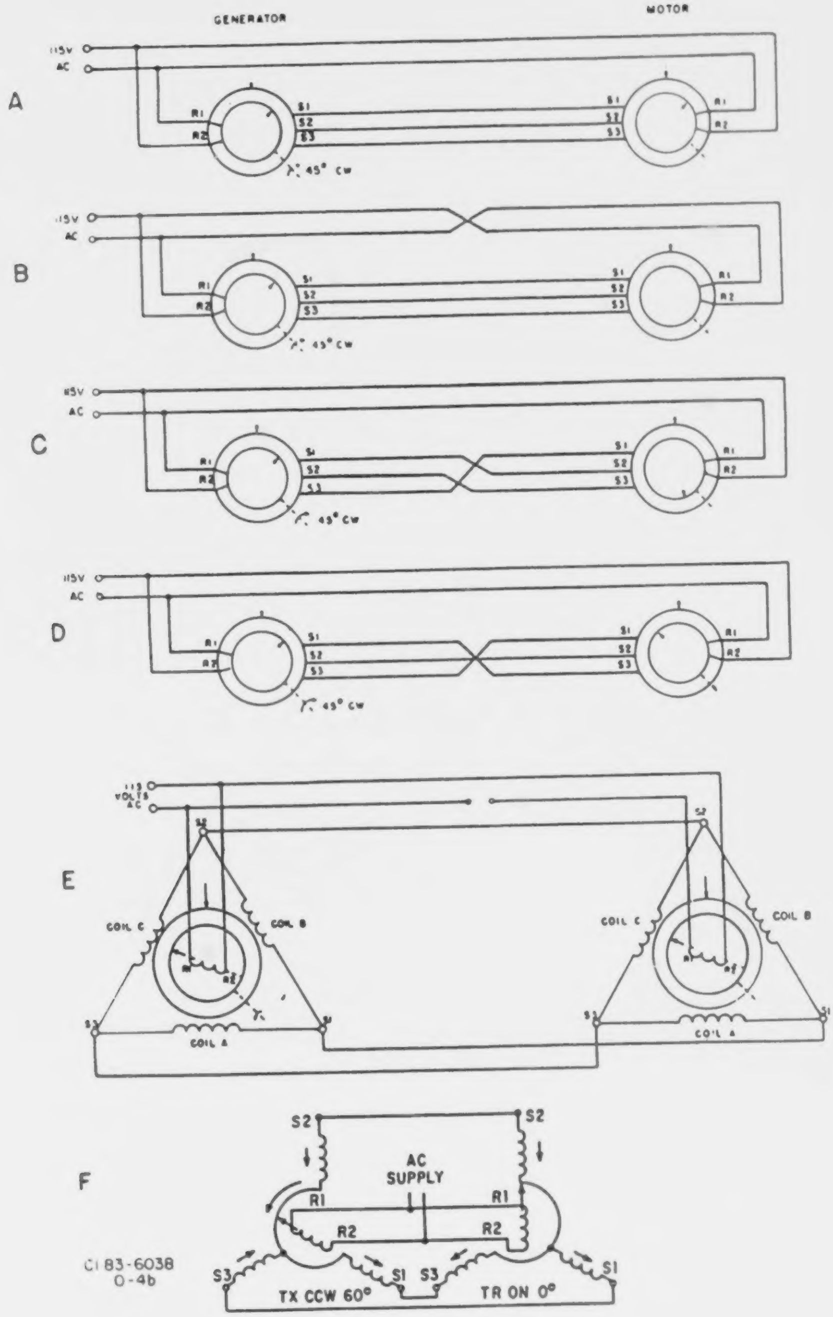

GENERATOR
MOTOR
A
B
C
D
E
F
115V
AC
R1
R2
S1
S2
S3
45° CW
115 VOLTS AC
COIL A
COIL B
COIL C
AC SUPPLY
TX CCW 60°
TR ON 0°
C183-6038
0-4b

Figure 8-34. Synchro circuit configuration.

3. Which of the circuits shown in figure 8-34 could cause the synchro receiver rotor to turn in either a clockwise or counterclockwise direction in a jerky or erratic manner?

4. After replacing the electrical connector on a synchro transmitter, the indication displayed by the receiver is reversed. What are the probable causes?

Binary Systems and Logic Circuit Elements

IT IS A RATHER widely accepted theory that the present 10-digit, or decimal, system of counting had its beginning in the use of man's fingers and toes to represent a quantity. In fact, the word "digit" is derived from the Latin word for "toe" or "finger." Though we seldom consider the use of any other number system, it shouldn't surprise us that a system based on a different number of "fingers" might be easier for an electronic computing machine to handle. Most modern digital computers use the binary number system as the machine language, while the decimal and octal systems are used in secondary roles, such as in program preparation or in computer readout devices.

This chapter discusses the binary and octal systems, the arithmetic operations (adding, subtracting, etc.) in both systems, and certain numbering codes developed from these systems. We will also discuss the composition and function of logic gates, inverters, delay lines, and flip-flops.

9-1. Binary Conversion

In this first section we will be discussing decimal and binary system characteristics and conversion between the systems. Then we will discuss direct binary mathematical operations and computer representation and manipulation of signed numbers. In the last part of this section we will discuss the octal system and several codes.

492. Define the various terms used with the decimal number system.

Decimal System Characteristics. There are two very important features of all modern number systems: the place value concept and the use of placeholders. Place value means simply that the value expressed by a digit depends on its position within a number. For example, the 3 in 30 means a different value than does the 3 in 300. It is this feature which allows us to use only 10 digits (0, 1, 2, 3, 4, 5, 6, 7, 8, 9) to represent any number, large or small, in the decimal system.

When the place value method was first developed, a space was used to indicate that a particular position was not being used. For example 204 was written 2 4 and 2004 was written 2 4. You can see that this method was confusing and subject to errors of interpretation. Does 2 4 represent 2004 or 20004? This defect in the system eventually led to the use of 0 as a placeholder. Although zero represents nothing, its use as a placeholder has greatly simplified the processes of mathematical computations.

We have said that the decimal system uses 10 symbols to represent numbers; other systems vary from this. For instance, the binary system uses two symbols (0 and 1) and the octal system uses eight symbols (0, 1, 2, . . . 7). The number of symbols used in any system is called the base, or radix, of the system. Thus, the decimal system is a base ten system.

Let's take a closer look at a base 10 number. A common method of writing is called "powers of 10." Thus, 10 × 10 × 10 may be written as 10^3 and is read as "10 cubed." The raised digit 3 tells how many times to use 10 as a factor. In the statement, $10^3 = 1000$, 10 is the base, 1000 is the power, and 3 is the exponent. The power, then, is equal to the product of the base used as a factor a number of times equal to the exponent. We may also say that the value of a digit in a number is the digit itself, raised to the power of the place it occupies. As an illustration, let's apply the base 10 number, 4203, to the powers of 10, as shown in figure 9-1. Multiplying each of the digits in our number (4203) by the base raised to the power of the place it occupies, we see that:

> The least significant digit (LSD), 3, in the units (10^0) column, express a value equal to 3 "ones" or 3 × 1.
> The 0 in the "tens (10^1) column expresses a value equal to 0 "tens" or 0 × 10.
> The 2 in the "hundred" (10^2) column expresses a value equal to 2 "hundred" or 2 × 10.
> The most significant digit (MSD), 4, in the "thousands" (19^3) column expresses a value equal to 4 "thousands" or 4 × 1000.

Thus, we find that the number 4203 is equal to 4 "thousands" plus 2 "hundreds" plus 0 "tens" plus 3 "ones."

So far we have dealt with a whole number, that is, one in which all discrete characters (digits) are to the left of the decimal point. A fractional number has the discrete characters to the right of the decimal pont. The first digit to the right of the decimal point is the MSD, while the last digit to the right is the LSD. Figure 9-2 illustrates fractional place values. Notice that the exponents are negative. Of course, much more might be said about the decimal system, and later we will refer to certain rules and procedures for manipulating decimal numbers. For the present, this brief review will help you understand certain characteristics of the binary numbering system.

Exercises (492):

1. What does "place value" mean?

488

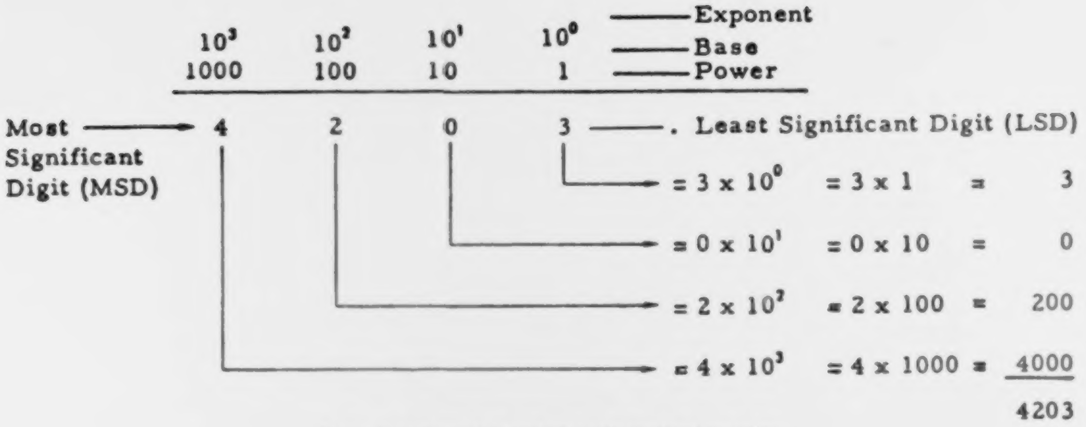

Exponent
Base
Power
10^3
1000
10^2
100
10^1
10
10^0
1
Most Significant Digit (MSD)
4
2
0
3
Least Significant Digit (LSD)
$= 3 \times 10^0 = 3 \times 1 = 3$
$= 0 \times 10^1 = 0 \times 10 = 0$
$= 2 \times 10^2 = 2 \times 100 = 200$
$= 4 \times 10^3 = 4 \times 1000 = 4000$
4203

Figure 9-1. Example of decimal whole number place value.

2. What number is used as a placeholder?

3. Define the term base, or radix.

4. In the statement $10^3 = 1000$, what number is the base? The power? The exponent?

5. The power of a number is equal to what?

6. In the number of 6178, what number is the MSD, and what number is the LSD?

493. State characteristics of the binary number system and clarify basic operations.

The Binary System. The binary system is now widely used in digital computers, primarily because it has only two discrete characters (1 and 0). This feature of the system closely parallels the operation of certain components of the digital computer. Relays and switches are bistable in nature; that is, they have two possible states. For example, a switch is either on or off, and a relay contact is either open or closed. As electronic tubes and solid-state devices replaced switches and relays in computers, designers realized that the effect of small variations in the

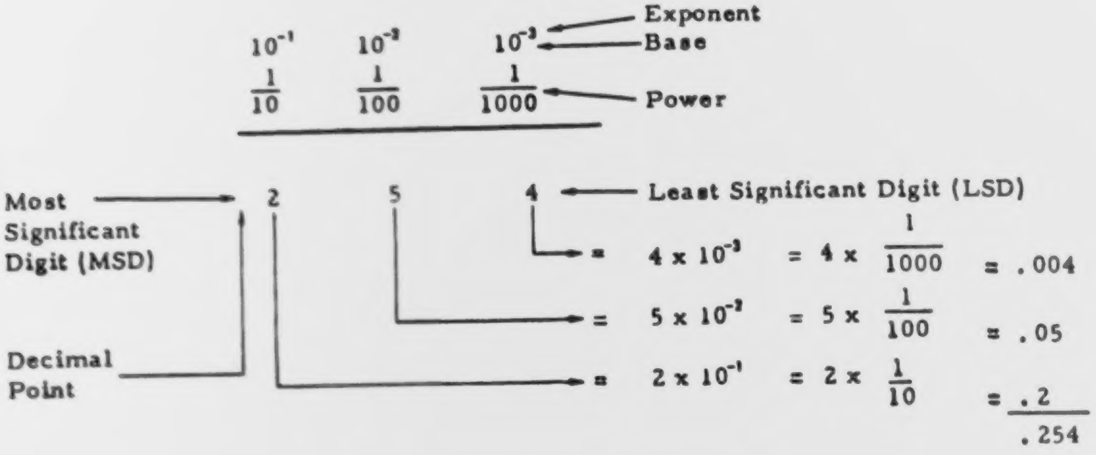

Exponent
Base
Power
10^{-1}
$\frac{1}{10}$
10^{-2}
$\frac{1}{100}$
10^{-3}
$\frac{1}{1000}$
Most Significant Digit (MSD)
Decimal Point
2
5
4
Least Significant Digit (LSD)
$= 4 \times 10^{-3} = 4 \times \frac{1}{1000} = .004$
$= 5 \times 10^{-2} = 5 \times \frac{1}{100} = .05$
$= 2 \times 10^{-1} = 2 \times \frac{1}{10} = .2$
.254

Figure 9-2. Example of decimal fraction place value.

characteristics of these new components could be overcome by operating these devices in a bistable manner. They designed circuitry so that these devices would essentially be in one of two states: conducting or nonconducting. The outputs of circuits containing these components will, of course, depend on the value of input signals, biasing, etc. For instance, when a tube or transistor is cut off, the circuit output could be zero voltage or a low voltage, representing a binary "0." With the same components conducting, the output could be a pulse, or high voltage, representing a binary 1. You can see, then, that the binary system, with its two discrete characters, is the number system most easily represented by bistable devices. Before we explore the binary system further, we must consider several points. First, since both the binary and decimal systems use the digits 1 and 0, we must have some method for determining whether a number is decimal or binary. Is 10 a decimal ten or a binary two? This problem is solved by using the base of the system as a subscript. Thus, $10_{(10)}$ tells us that this number is a decimal "ten," and $10_{(2)}$ tells us that this is a binary "two." Another important point is that $10_{(10)}$ is read as "ten," while $10_{(2)}$ is read "one-zero." The number $1101_{(2)}$ is read as "one-one-zero-one." Can we say that $1101_{(2)}$ is a 4-digit binary number? Yes. It is, however, more common to say that $1101_{(2)}$ is a 4-bit number. "Bit" is a contraction of "binary digit." We will use this term throughout the rest of our discussion.

The binary system, like the decimal system, uses zero as a placeholder and the place value method of representing numbers. Just as we can write a decimal number in powers of 10, we can write binary numbers in powers of 2. In the statement $2^3 = 8$, 2 is the base, 8 is the power, and 3 is the exponent. We can also say that the value expressed by a bit is equal to the bit multiplied by the power of the place it occupies. As an example, let's find the decimal equivalent of the binary number 1101001 using the powers of 2, as shown in figure 9-3. After multiplying each of the bits by the power of the place the bit occupies, and then adding these values toegther, we see that $1101001_{(2)}$ is equal to $105_{(10)}$. Note in figure 9-3 that as the exponent increases by one, the power doubles. This is characteristic of the base two system.

As shown in figure 9-4, the representation of fractional numbers (those numbers whose bits lie to the right of the binary point, decimal point, in base 10) is also similar to the decimal method. Note that as the negative exponent decreases by one (for example, from 2^{-2} to 2^{-3} or from 2^{-5} to 2^{-6}), the power is halved.

When we use the powers of 2 in figures 9-3 and 9-4, we actually converted a binary number to its decimal equivalent. This method of converting from binary to decimal is called the addition method. You will study this and other binary to decimal conversion methods later.

Exercises (493):

1. Why is the binary system best for the digital computer?

2. In the base two system, as the exponent increases by 1, what happens to the power?

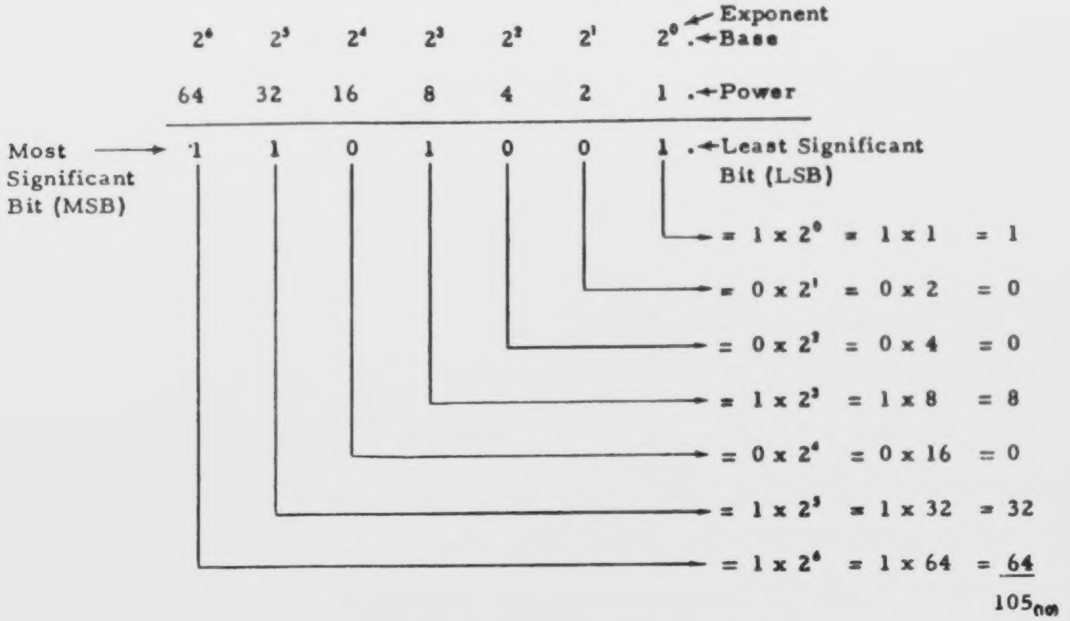
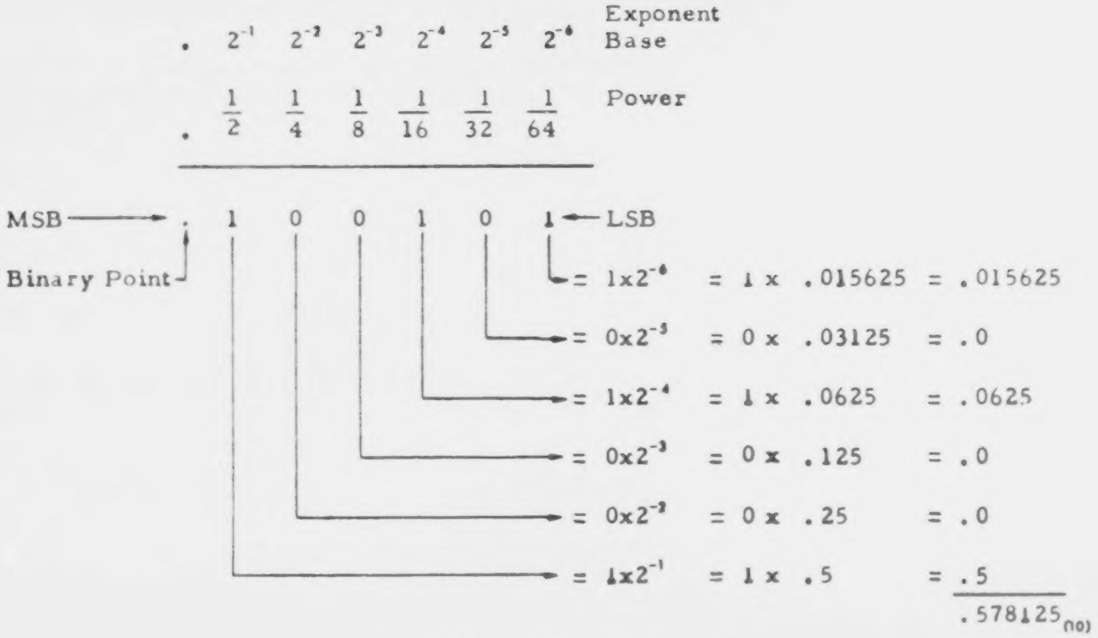


Figure 9–3. Example of binary whole number place value.



Exponent
Base
Power
. 2^{-1} 2^{-2} 2^{-3} 2^{-4} 2^{-5} 2^{-6}
. $\frac{1}{2}$ $\frac{1}{4}$ $\frac{1}{8}$ $\frac{1}{16}$ $\frac{1}{32}$ $\frac{1}{64}$
MSB
. 1 0 0 1 0 1
LSB
Binary Point
$= 1 \times 2^{-6} = 1 \times .015625 = .015625$
$= 0 \times 2^{-5} = 0 \times .03125 = .0$
$= 1 \times 2^{-4} = 1 \times .0625 = .0625$
$= 0 \times 2^{-3} = 0 \times .125 = .0$
$= 0 \times 2^{-2} = 0 \times .25 = .0$
$= 1 \times 2^{-1} = 1 \times .5 = .5$
$.578125_{(10)}$

Figure 9–4. Example of binary fraction place value.

3. What happens to the power when the negative exponent decreases by 1 (from 2^{-2} to 2^{-3})?

494. Convert decimals to binary numbers by the division method.

Decimal to Binary Conversion. There are several methods of converting decimal numbers to binary form, but we will consider only two of them: the dividion method of converting whole numbers and the multiplication method of converting fractions.

Division method (whole numbers). This is a versatile, easily used method that works well on any size decimal whole number. It involves repeatedly dividing the decimal number by the radix (2) of the binary system according to the following rules (see fig. 9-5):

(1) Divide the decimal number by 2. The remainder (0 or 1 when dividing by 2) becomes the least significant bit (LSB) of the binary number.

(2) Divide the quotient of the first division by 2. The remainder becomes the next bit in the binary number.

(3) Continue to divide by 2 until the final quotient is 0. The remainder of each division step will become a bit in the binary number.

The final remainder is the most significant bit (MSB) of the binary equivalent number. Let's apply these rules and convert $142_{(10)}$ to its binary equivalent (see fig. 9-6):

Step 1. Following rule 1, we divide 142 by 2. The remainder (0) becomes the LSB of the binary number.

Step 2. Following rule 2, we divide the quotient of the first division (71) by 2. The remainder (1) becomes the next bit in the binary number. The following steps are directed by rule 3.

Step 3. Dividing 35 by 2 gives a quotient of 17 and a remainder of 1. The remainder (1) becomes the next bit in teh binary number.

Step 4. Dividing 17 by 2 gives us a quotient of 8 and a binary bit of 1.

Step 5. Dividing 8 by 2 we get a binary bit of 0.

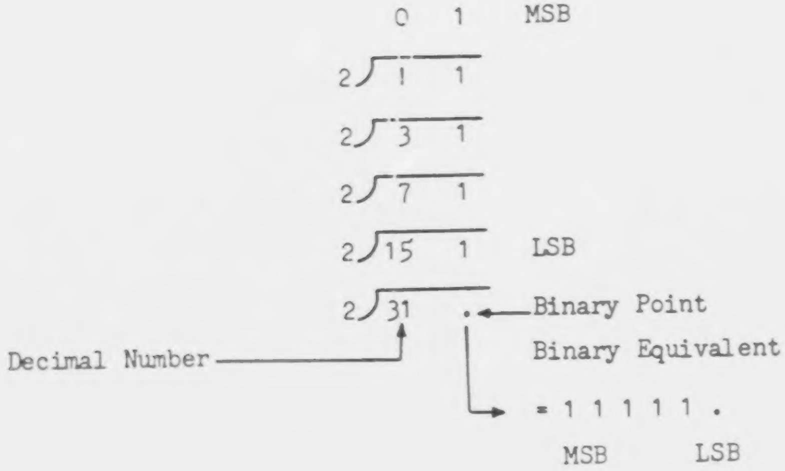
Step 6. Dividing 4 by 2 gives a binary bit of 0.

Step 7. Dividing 2 by 2 gives us a binary bit of 0.

Step 8. Dividing 1 by 2 gives us a final quotient of 0 and a remainder of 1. This remainder (1) becomes the MSB of the binary number equivalent to $142_{(10)}$.

This completes the conversion. To check our answer, we write the binary number 10001110, and above each bit indicate the position held by the bit as shown below. Since this is a whole number, the LSB occupies the 2^0 position; the next bit occupies ^{1} position, and so on. The MSB occupies the 2^7 position. Now, referring to table 9-1, we add together the powers of all positions occupied by binary 1. Since 0s are merely placeholders, we ignore them. The 2^7 position is occupied by a 1, and the table shows that the 2^7 position has a power of 128. This will be one of the powers which we will add together. Positions 2^6 through 2^4 are occupied by 0s, so we will ignore them. Position 2^3 is occupied by a 1 and has a power of 8. Position 2^2 is occupied by a 1 and has a power of 4. Position 2^0 is occupied by a placeholder and may be ignored. Adding together the powers of the positions occupied by 1s, we find that $128 + 8 + 4 + 2 = 142_{(10)}$. This tells us that we made a correct conversion.

Position	2^7	2^6	2^5	2^4	2^3	2^2	2^1	2^0	
Binary number	1	0	0	0	1	1	1	0	. binary point
	MSB							LSB	



0 1 MSB
2 1 1
2 3 1
2 7 1
2 15 1 LSB
2 31 .
Binary Point
Decimal Number
Binary Equivalent
= 1 1 1 1 1 .
MSB LSB

Figure 9–5. Division method—decimal to binary conversion.

Exercises (494):

Convert these numbers to binary form and check your answers.

1. $76_{(10)}$

2. $212_{(10)}$

3. $63_{(10)}$

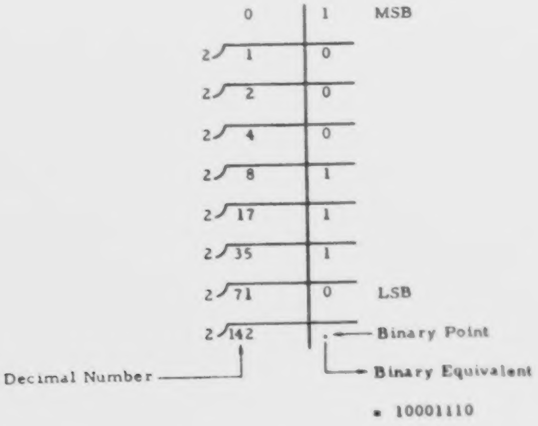
4. $21_{(10)}$

5. $1409_{(10)}$

6. $855_{(10)}$

495. Convert decimals to binary numbers by multiplication.

Multiplication Method (Fractional Numbers). This method, adapable to fractions of all sizes, consists of a series of multiplication steps. The decimal fraction is repeatedly multiplied by 2, and the digit (1 or 0 when multiplying by 2) generated to the left of the decimal point in the product becomes a bit in the equivalent binary number. The example in figure 9-7 shows the conversion of the decimal fraction .4375 to binary form. The following rules are used in this conversion process.



0 1 MSB
2 1 0
2 2 0
2 4 0
2 8 1
2 17 1
2 35 1
2 71 0 LSB
2 142 .
Binary Point
Decimal Number
Binary Equivalent
= 10001110

Figure 9–6. Example of decimal to binary conversion—whole number.

TABLE 9-1

TABLE OF POWERS OF 2

2^n	n	2^{-n}
1	0	1.0
2	1	0.5
4	2	0.25
8	3	0.125
16	4	0.062 5
32	5	0.031 25
64	6	0.015 625
128	7	0.007 812 5
256	8	0.003 906 25
512	9	0.001 953 125
1 024	10	0.000 976 562 5
2 048	11	0.000 488 281 25
4 096	12	0.000 244 140 625
8 192	13	0.000 122 070 312 5
16 384	14	0.000 061 035 156 25
32 768	15	0.000 030 517 578 125
65 536	16	0.000 015 258 789 062 5
131 072	17	0.000 007 629 394 531 25
262 144	18	0.000 003 814 697 265 625
524 288	19	0.000 001 907 348 632 812 5
1 048 576	20	0.000 000 953 674 316 406 25
2 097 152	21	0.000 000 476 837 158 203 125
4 194 304	22	0.000 000 238 418 579 101 562 5
8 388 608	23	0.000 000 119 209 289 550 781 25
16 777 216	24	0.000 000 059 604 644 775 390 625
33 554 432	25	0.000 000 029 802 322 287 695 312 5
67 108 864	26	0.000 000 014 901 161 193 847 656 25
134 217 728	27	0.000 000 007 450 580 596 923 828 125
268 435 456	28	0.000 000 003 725 290 298 461 914 062 5
536 870 912	29	0.000 000 001 862 645 149 230 957 031 25
1 073 741 825	30	0.000 000 000 931 322 574 615 478 515 625
2 147 483 648	31	0.000 000 000 465 661 287 307 739 257 812 5
4 294 967 296	32	0.000 000 000 232 830 643 653 869 628 906 25
8 589 934 592	33	0.000 000 000 116 415 321 826 934 814 453 125
17 179 869 184	34	0.000 000 000 058 207 660 913 467 407 226 562 5
34 359 738 368	35	0.000 000 000 029 103 830 456 733 703 613 281 25

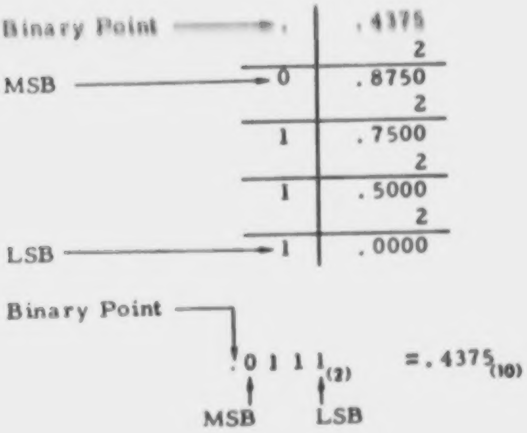


Figure 9–7. Multiplication method—decimal to binary conversion.

(1) Multiply the decimal fraction by 2. If the product is greater than 1, the whole part of the product (1 or 0 when multiplying by 2) becomes the MSB of the binary equivalent and is dropped from the product. If the product is less than 1, a 0 becomes the binary MSB.

(2) Multiply the fractional part of the product of the first multiplication by 2. If a whole number (1 when multiplying by 2) is generated to the left of the decimal point, it becomes the next bit of the binary number and is dropped from the product. If no 1 was generated, the binary bit will be a 0.

(3) Continue multiplying the fractional portion of the products by 2. The digit to the left of the decimal point of each product will be the binary bit for that step. The degree of accuracy desired will determine the number of multiplication steps to be performed. The binary bit generated by the last multiplication step is the LSB.

To clarify the use of these rules, let's convert the decimal fraction .2931 to binary form in a step-by-step process (fig. 9-8):

Step 1. Following rule 1, we multiply the decimal fraction (.2931) by 2. Since the product (.5862) is less than 1, the digit to the left of the decimal point is a 0. This 0 becomes the MSB of the binary equivalent.

Step 2. Following rule 2, we multiply the fractional part of the first product (.5862) by 2. This time the product (1.724) is greater than 1; therefore, the 1 to the left of the decimal point becomes the next bit of the binary number.

Step 3. We now multiply the fractional part (.1724) of the current product by 2. Since the product (0.3448) of this multiplication step is less than 1, the 0 to the left of the decimal point becomes the next binary bit.

Step 4. Multiplying the fractional part (.3448) of the current product by 2, we get a product of 0.6896. The 0 to the left of the decimal point becomes the next binary bit.

Step 5. Multiplying .6896 by 2 gives us a product of 1.3792. The 1 becomes a binary bit.

Step 6. Multiplying .3792 by 2 gives us a product of 0.7584 and a binary bit of 0.

Step 7. Multiplying .7584 by 2 gives us a product of 1.5168 and a binary bit of 1.

Step 8. Multiplying .5168 by 2 gives us a product of 1.0336 and a binary bit of 1.

At this point, our conversion is accurate to eight binary places, since we have eight binary bits. We will stop here, and following rule 3, the digit (1) to the left of the decimal point in the final product (1.0336) wil be designated the LSB of the binary number. We could continue the multiplication steps until we attain any desired degree of accuracy. However, the binary equivalent will never be exactly equal to the decimal fraction unless the fractional portion of the final product consists of all zeros, as shown in figure 9-7. To check our conversion and see just how closely $.01001011_{(2)}$ compares to $.2931_{(10)}$, we will use table 9-1.

First, we write the binary number (.01001011) and indicate the positions occupied by each bit. This is a fractional number, so the MSB will occupy the 2^{-1} position as shown below:

Position	2^{-1}	2^{-2}	2^{-3}	2^{-4}	2^{-5}	2^{-6}	2^{-7}	2^{-8}
Binary numbers	0	1	0	0	1	0	1	1

Now we add together the powers of each position occupied by a 1 in the binary number. Since zeros are placeholders, we gnore them. Table 9-1 shows that position 2^{-2} has power of .25; 2^{-5} has a power of .03125; 2^{-7} has a power of .0068125; and 2^{-8} has a power of .00390625. Adding these powers together, we find that $.01001011_{(2)}$ equals $.29296875_{(10)}$

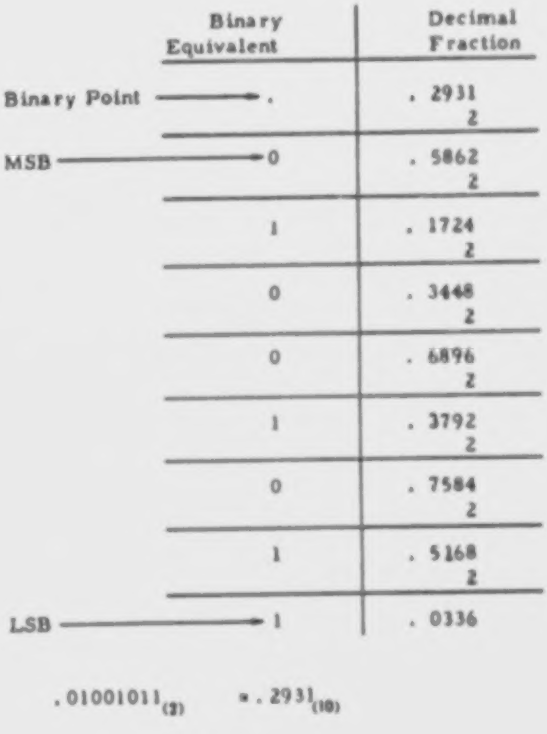


Figure 9–8. Example of decimal to binary conversion—fraction.

.25
.03125
.0078125
.00390625
.29296875

Subtracting .29296875 from the decimal fraction .2931, which we initially converted to binary equivalent, we find that the inaccuracy is only slightly more than .001

$$\begin{array}{r} .2931 \\ (-)\ .29296875 \\ \hline .00013125 \end{array}$$

We haven't yet discussed converting mixed decimal numbers (numbers that have a whole part and a fractional part) to binary. To convert a mixed number to binary, you must first separate the number into its whole and fractional parts; convert each part, using the appropriate method; and then add together the equivalent binary parts. For instance, in the decimal number 16.25, the whole part (16) is converted to $10000_{(2)}$ by using the division method. Then, the fractional part is converted to $.01_{(2)}$ by using the multiplication method. The conversion is completed by adding together these two binary parts: $10000_{(2)} + .01_{(2)} = 10000.01_{(2)}$. The equivalent of $16.25_{(10)}$ is $10000.01_{(2)}$.

This ends our discussion of decimal to binary conversion methods. You will find that your knowledge of the preceding material will be strengthened by the following discussion of binary-to-decimal conversion methods.

Exercises (495):

Convert these fractions to an accuracy of six binary places, if necessary.

1.

2. $75_{(10)}$

3. $23.125_{(10)}$

4. $175.789_{(10)}$

5. $69.963_{(10)}$

496. Convert binary whole numbers to decimal whole numbers by the double-dabble method.

Binary-to-Decimal Conversion. For converting binary numbers to decimal form, there is again a choice of several methods. The two methods we will discuss, double-dabble (whole numbers) and addition (fractional numbers), are the methods that are most easily adapted to all sizes of binary numbers.

Double-dabble method (whole numbers). The double-dabble method, sometimes called synthetic division, is a repeated series of addition and multiplication steps. In studying the following rules, refer to figure 9-9.

(1) Add "0" to the MSB of the number to be converted.

(2) Multiply the sum (from rule 1) by the base of the number being converted.

(3) Add the product (from rule 2) to the next lower significant bit of the number.

(4) Multiply the sum (from rule 3) by the base.

(5) Add the product (from rule 4) to the next lower significant bit. Repeat the add-multiply progression until all bits except the LSB have been acted on.

(6) The final step is to add the product of the last multiplication step to the LSB. This sum is the decimal equivalent of the binary number.

To apply the double-dabble rules in a step-by-step process, convert the binary number of 110100 to its decimal equivalent, as shown in figure 9-10.

Step 1. Add 0 to the MSB. This gives a sum of 1.

Step 2. Multiplying this sum (1) by 2 gives a product of 2.

Step 3. Adding the product (2) to the next lower significant digit (1) gives a sum of 3.

Step 4. Multiply this sum (3) by 2.

Step 5. The product (6), added to the next lower bit (0), gives a sum of 6.

Step 6. Continuing the process, we multiply 6 × 2.

Step 7. When we add the produce (12) to the next lower significant bit (1), we derive a sum of 13.

Step 8. Multiplying 13 × 2 gives a product of 26.

Step 9. Adding the product (26) to 0 gives a sum of 26.

Step 10. Multiplying the sum (26) by 2 gives a product of 52. We have now operated on all bits except the LSB.

Step 11. The last step is to add the final product (52) to the LSB (0), which gives a sum of 52. This sum is the decimal equivalent of $110100_{(2)}$.

Exercises (496):

Convert the following binary numbers to decimals. Check

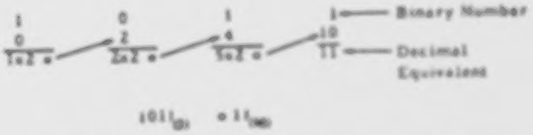


Figure 9-9. Double-dabble method—binary to decimal conversion.

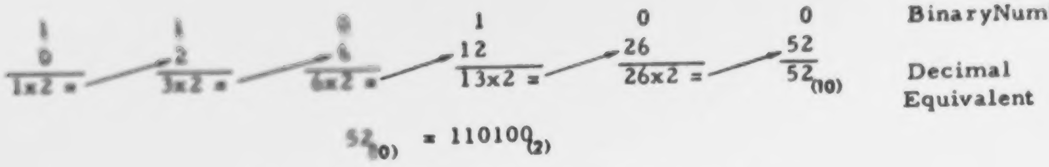


Figure 9-10. Example of binary to decimal conversion—whole number.

your work by converting your answers back to binary, using the division method.

1. $1101_{(2)}$

2. $1000_{(2)}$

3. $10111_{(2)}$

4. $101100_{(2)}$

5. $111111_{(2)}$

497. Convert binary numbers to decimals by the addition (fractional numbers) method.

We have one more conversion method to discuss. This is the addition method of converting binary fractions to decimal form. As we proceed with the discussion, you will remember that we have already used this method to check our decimal to binary conversions.

Addition Method (Fractions). As you have seen, this method requires only that you add together the powers of the positions occupied by 1s in the binary number. The powers are shown in table 9-1. You might find that writing the binary number and indicating above each bit the position it occupies will help to eliminate errors. As an example, we will convert the binary fraction .10011 to decimal form:

Position	2^{-1}	2^{-2}	2^{-3}	2^{-4}	2^{-5}
Binary number	1	0	0	1	1

Step 1. First, write the binary number and indicate bit positions.

Step 2. Referring to table 9-1, we find that 2^{-1} has a power of .5.

Step 3. Again using the table, we find that 2^{-4} has a power of .0625.

Step 4. We find that 2^{-5} has a power of .03125.

Step 5. Now we add together the powers we have extracted from the table: .5 + .0625 = .59375. Therefore, $.59375_{(10)} = .10011_{(2)}$. The conversion is now complete.

Exercises (497):

Convert the binary numbers to decimal form. To convert the mixed numbers, treat each part (whole and fractional) separately and then add the results to complete the conversion.

1. $.110001_{(2)}$

2. $.00011_{(2)}$

3. $11.11010_{(2)}$

4. $1011.01000_{(2)}$

5. $1111.10111_{(2)}$

498. Add binary numbers.

Direct Binary Mathematical Operations. You can add, subtract, multiply, and divide binary numbers just as you can in the decimal system. Actually, binary arithmetic is easier to learn than decimal arithmetic, because you work with only 2 discrete characters rather than 10. We will first apply the direct mathematical operations to positive numbers. Then we will discuss how the computer adds and subtracts signed numbers.

Binary addition. The binary addition table is:

0 + 0 = 0
0 + 1 = 1
1 + 1 = 0 with a carry of 1

Addition starts in the lowest order column, and carries are performed just as they are in the decimal system. When you add a column of numbers, you must carry a 1 over to the next higher order column whenever the sum exceeds the maximum count (7). That is, for every two 1s in a column, you must carry a 1 to the next column and start the count again at 0. Follow this step-by-step solution to add 1011 and 1110:

Column E	*Column D*	*Column C*	*Column B*	*Column A*
1 carry	1 carry	1 carry		
	1	0	1	$1_{(2)} = 11_{(10)}$
	1	1	1	$0_{(2)} = 14_{(10)}$
1	1	0	0	$1_{(2)} = 25_{(10)}$

Step 1. In column A, 1 + 0 = 1.

Step 2. In column B, 1 + 1 = 0, and a 1 is carried to column C.

Step 3. In column C, 1 + 0 = 1 + 1 (the carry from column B) = 0, with a carry to column D.

Step 4. In column D, 1 + 1 = 0 with a carry to column E. This 0 + 1 (the carry from column C) = 1.

Step 5. The 1 in column E is brought down and becomes the MSB of the sum.

When adding binary mixed numbers, write the numbers with the binary points in one column, just as you would with decimal numbers. The addition process still starts with the lowest order column, and carries can be made across the binary point. The example below illustrates these principles.

Example:

1111		Carries
11111 1		Carries
111.11	=	$7.75_{(10)}$
10.10	=	$2.5_{(10)}$
101.01	=	$5.25_{(10)}$
+ 111.11	=	$7.75_{(10)}$
10111.01	=	$23.25_{(10)}$

Exercises (498):

Add the following binary numbers, then check your answers by converting the binary numbers to decimal form and reworking the problems.

1.
$$\begin{array}{rr} & 1100111 \\ (+) & 10010 \\ \hline \end{array}$$

2.
$$\begin{array}{rr} & 10.111 \\ (+) & 101.001 \\ \hline \end{array}$$

3.
$$\begin{array}{rr} & 10111.10 \\ (+) & 110.01 \\ \hline \end{array}$$

4.
$$\begin{array}{rr} & 10000.001 \\ & .100 \\ (+) & 111.110 \\ \hline \end{array}$$

5.
$$\begin{array}{rr} & 111.11 \\ (+) & 100.11 \\ \hline \end{array}$$

6.
$$\begin{array}{rr} & 1011.10 \\ & 1100.01 \\ (+) & 10100.11 \\ \hline \end{array}$$

499. Subtract binary numbers.

Binary Subtraction. Direct binary subtraction is similar to decimal subtraction. This is the binary subtraction table:

0 − 0 = 0
1 − 0 = 1
1 − 1 = 0
0 − 1 = 1 with a borrow of 1.

As is true in the decimal system, the only time that a borrow is necessary is in subtracting a larger bit from a smaller bit. When a borrow is made in the decimal system, you borrow a power of 10 from the next high-order column containing a digit other than a 0. This digit is reduced by 1, and a 1 is placed to the left of the borrowing digit. For instance, in the example below, to subtract 5 from 22, the 2 in column B is reduced to 1 and a 1 is placed to the left of the 2 in column A. The 5 is then subtracted from 12, giving a difference of 7 for that column. The 1 remaining in column B is brought down to make the total difference equal 17.

Example:

$$\begin{array}{rcc} & \overset{1}{\cancel{2}} & \overset{12}{\cancel{2}} \\ (-) & & 5 \\ \hline & 1 & 7 \end{array}$$

In binary subtraction, a power of 2 is borrowed, but the procedure is identical to borrowing a power of 10 in decimal subtraction. Perhaps the easiest way to do it is to think decimal, but write binary, when you borrow. Here is a step-by-step solution to the problem $11001_{(2)}$ minus $10_{(2)}$:

	E	D	C	B	A		
			1	10			
		0	10				
Minuend	1	~~1~~	~~0~~	~~0~~	1	=	$25_{(10)}$
Subtrahend (−)				1	0	=	$2_{(10)}$
Difference	1	0	1	1	1	=	$23_{(10)}$

Step 1. In column A, 1 - 0 = 1.

Step 2. In column B, the 1 in the subtrahend is larger than the 0 in the minuend, so you must borrow. Since column D is the first higher-order column containing a 1, you must borrow from there and transfer the borrow through successive columns until you have it in column B. To perform the borrow, reduce the bit being borrowed from by 1 (from 1 to 0), and change column C to 10. Column C now has a borrow from column D, but you need to transfer this borrow to column B. Here is where it helps to think decimal. In column C, you now have 10, which is equal to 2 in decimal. To borrow from this, reduce the 2 (10) by 1, and you have 1 left. Change column B to 10, and the borrow is completed.

Step 3. In column B, you how have 10 (equal to 2) in the minuend. Thinking decimal, subtract the 1 in the subtrahend from 2 (10), and the difference is 1.

Step 4. There are no more bits in the subtrahend, so bring all remaining bits in the minuend down to become part of the difference.

Exercises (499):

Before you proceed to the discussion of binary multiplication, solve the binary subtraction problems in these exercises. In the mixed numbers, you can borrow across the binary point just as you would in decimal subtraction. Check your answers by converting the numbers to decimal and reworking the problems.

1. 1001
(−) 101

2. 10000
(−) 11

3. 110.01
(−) 100.10

4. 101.11
(−) 11.11

5. 1001.10
(−) 1001.01

6. .101
(−) .001

500. Multiply binary numbers.

Binary Multiplication. Unlike its decimal counterpart, the binary multiplication table is very short. The three entries are:

$0 \times 0 = 0$
$0 \times 1 = 0$
$1 \times 1 = 1$

The simplicity of binary multiplication lies in the fact that it is only necessary to copy the multiplicand if the multiplier digit is a 1, or write all 0s if the multiplier digit is a 0. The following examples of binary multiplication illustrate the process. Note that the partial products are added as in binary addition, and the binary point in the final product is positioned according to the same rule you would use to position the decimal point in a decimal product.

Examples:

Multiplicand	1100	=	$12_{(10)}$
Multiplier	1010	=	$10_{(10)}$
	0000		00
	1100		12
	0000		
	1100		
	111100	=	$120_{(10)}$
Multiplicand	1.01	=	$1.25_{(10)}$
Multiplier	10.1	=	$2.5_{(10)}$
	101		625
	000		250
	101		
	11.001	=	$3.125_{(10)}$

Exercises (500):

Multiply, then check your answers by converting the numbers to decimal form and reworking the problems.

1. 1101
(×) 101

2. 100.10
(×) .11

3. 111.11
(×) 10.11

4.
$$\begin{array}{r} 1011 \\ (\times)\quad 111 \\ \hline \end{array}$$

5.
$$\begin{array}{r} 11101 \\ (\times)\quad 10000 \\ \hline \end{array}$$

6.
$$\begin{array}{r} 110.01 \\ (\times)\quad 10.01 \\ \hline \end{array}$$

501. Divide binary numbers.

Binary Division. Binary division is also quite simple. As in any number system, dividing by zero is meaningless, so the complete table has only two entries. These are:

$0 \div 1 = 0$
$1 \div 1 = 1$

Binary division is similar to decimal division except that the subtraction steps are done by the rules for binary subtraction. The binary points are placed by the same rules you would use in a decimal problem. The following examples illustrate binary division.

Binary	*Decimal*
$\begin{array}{r} 101 \\ 101\overline{)11001} \\ \underline{101} \\ 101 \\ \underline{101} \\ 0 \end{array}$	$\begin{array}{r} 5 \\ 5\overline{)25} \\ \underline{25} \\ 0 \end{array}$
$\begin{array}{r} 11 \\ 11\overline{)1001} \\ \underline{11} \\ 11 \\ \underline{11} \\ 0 \end{array}$	$\begin{array}{r} 3 \\ 3\overline{)9} \\ \underline{9} \\ 0 \end{array}$
$\begin{array}{r} 110.001 \\ 100\overline{)11000.1} \\ \underline{100} \\ 100 \\ \underline{100} \\ 0.100 \\ \underline{100} \\ 0 \end{array}$	$\begin{array}{r} 6.125 \\ 4\overline{)24.500} \\ \underline{24} \\ 5 \\ \underline{4} \\ 10 \\ \underline{8} \\ 20 \\ \underline{20} \\ 0 \end{array}$

You should now have a good understanding of the binary number system and should be able to perform the mathematical operations with no aids other than pencil and paper. If you feel that you do not understand some specific aspect of the binary system, restudy the applicable portion of this chapter. Your knowledge of the binary system will be strenghtened by the material in the following discussion of the octal number system and will help you learn this system.

Exercises (501):

Carry out the answers to four decimal places, it necessary.

1. $111 \div .01$

2. $1010 \div 111$

3. $110 \div 10.1$

4. $10001 \div 101.11$

5. $1011 \div 101$

6. $1000 \div 10$

502. Convert numbers between octal and decimal forms.

Characteristics of the Octal System. While the binary system is well suited to its use as machine language, it requires up to 3 or 4 times as many digits to represent a specific magnitude as does the decimal system. A large number of 1s and 0s in a row are difficult to handle and are easily misinterpreted. These disadvantages are avoided by using the octal system to represent binary numbers in computer readout devices and in preparing programs. The octal system's advantages over the decimal system for these purposes will become readily apparent as we discuss converting binary numbers to octal form. The major difference between the two systems is the base. The octal system uses eight symbols (0, 1, 2, 3, 4, 5, 6, and 7) to represent numbers and is therefore a base (radix) 8 system. Octal numbers can be written in powers of 8. Thus, $8 \times 8 \times 8 = 512$ may be written $8^3 = 512$. The value of a digit in an octal number is equal to the digit multiplied by the power of the place it occupies. Figure 9-11 shows how to find the

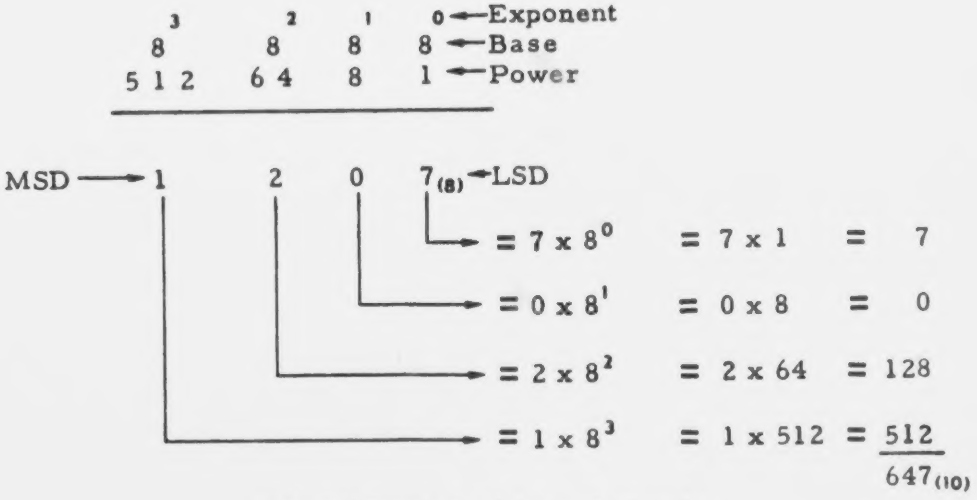


Figure 9–11. Example of octal whole number place value.

decimal value of $1207_{(8)}$, using the powers of 8. Table 9-2 gives a more complete table of powers of 8 and the binary and octal equivalent of decimal numbers 0 through 27.

Decimal to octal conversion. You should have no trouble learning to convert decimal numbers to octal form, because you use the same methods you do to convert decimal to binary; that is, the division method to convert whole numbers and the multiplication method to convert fractions. The only difference is that you will multiply or divide by 8 rather than 2. The examples in figure 9-12 show the conversion process. You might find it helpful to refer to the rules listed in objectives 494 and 495 for whole numbers and fractions as you study the examples.

Octal to decimal conversion. The two methods used for converting binary to decimal are also used to convert octal to decimal. The use of these methods, double-dabble for whole numbers and addition for fractions, is shown in figure 9-13. Refer to objective 496 for the double-dabble rules as you study the example of whole number conversion. The addition method merely involves adding together the values of the digits in the octal fraction. A 0 has no value since it is only a placeholder.

Exercises (502):

1. $113_{(10)} = ?_{(8)}$

2. $478_{(10)} = ?_{(8)}$

3. $52.42_{(10)} = ?_{(8)}$

4. $1496.1416_{(10)} = ?_{(8)}$

5. $76_{(8)} = ?_{(10)}$

6. $152_{(8)} = ?_{(10)}$

7. $749.16_{(8)} = ?_{(10)}$

8. $224.37_{(8)} = ?_{(10)}$

503. Convert numbers between octal and binary forms.

Binary-Octal-Binary Conversion. The simplest way to convert between binary and octal forms is by inspection. The number to be converted is inspected, and a direct substitution is made. This direct substitution is possible because a natural relationship between the binary and octal systems allows any octal digit to be represented by just three binary bits and any combination of three 1s and 0s to be represented by just one octal digit.

To convert a binary number to octal form, separate the binary number into groups of three bits, starting at the binary point. The extreme left and right groups can be filled in with 0s if necessary, since 0s to the left of the digits ahead of the radix point and 0s to the right of the digits behind the radix point have no meaning. Then, for each

TABLE 9–2
TABLE OF POWERS OF 8, DECIMAL, OCTAL, AND BINARY EQUIVALENTS

8^n	n	8^{-n}
1	0	1.0
8	1	0.125
64	2	0.015 625
512	3	0.001 953 125
4 096	4	0.000 255 140 625
32 768	5	0.000 030 517 578 125
262 144	6	0.000 003 814 697 265 625
2 097 152	7	0.000 000 476 837 158 203 125
16 777 216	8	0.000 000 059 604 644 775 390 625

TABLE OF POWERS OF 8

DECIMAL	OCTAL	BINARY	DECIMAL	OCTAL	BINARY
00	00	000 000	14	16	001 110
01	01	000 001	15	17	001 111
02	02	000 010	16	20	010 000
03	03	000 011	17	21	010 001
04	04	000 100	18	22	010 010
05	05	000 101	19	23	010 011
06	06	000 110	20	24	010 100
07	07	000 111	21	25	010 101
08	10	001 000	22	26	010 110
09	11	001 001	23	27	010 111
10	12	001 010	24	30	011 000
11	13	001 011	25	31	011 001
12	14	001 100	26	32	011 010
13	15	001 101	27	33	011 011

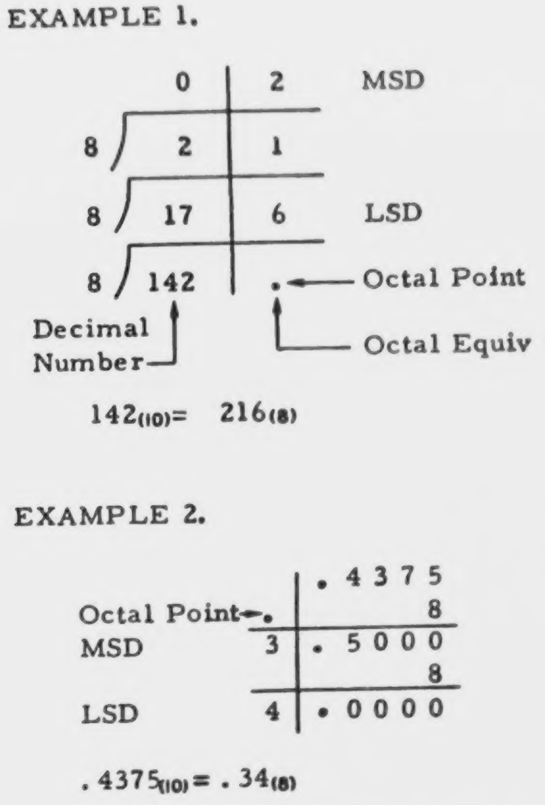

EXAMPLE 1.
0
2
MSD
8
2
1
8
17
6
LSD
8
142
. Octal Point
Decimal Number
Octal Equiv
142(10)= 216(8)
EXAMPLE 2.
. 4 3 7 5
Octal Point .
8
MSD
3
. 5 0 0 0
8
LSD
4
. 0 0 0 0
. 4375(10) = . 34(8)

Figure 9-12. Examples of decimal to octal conversion.

group of three bits, substitute the equivalent octal digit. For example, convert $11100.111_{(2)}$ as shown in figure 9-14.

To convert an octal number to binary form, separate the octal digits and replace each digit by its equivalent group of three binary bits. For example, convert $271.43_{(8)}$ to binary form, as shown in figure 9-15.

Exercises (503):

Convert the binary numbers to their octal form and the octal numbers to binary form.

1. $1110.10_{(2)} = ?_{(8)}$

2. $101101.011_{(2)} = ?_{(8)}$

3. $10.01110_{(2)} = ?_{(8)}$

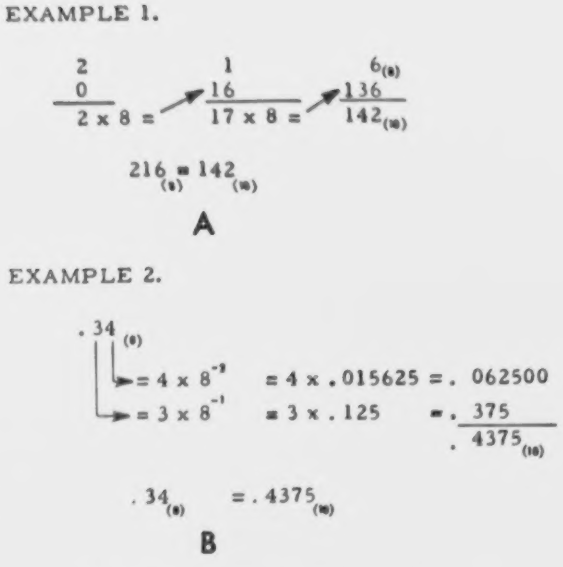

EXAMPLE 1.
2
0
2 x 8 =
1
16
17 x 8 =
6(8)
136
142(10)
216(8) = 142(10)
A
EXAMPLE 2.
. 34(8)
= 4 x 8^-2
= 4 x .015625 = . 062500
= 3 x 8^-1
= 3 x . 125
= . 375
. 4375(10)
. 34(8) = . 4375(10)
B

Figure 9-13. Examples of octal to decimal conversion.

4. $101101.101_{(2)} = ?_{(8)}$

5. $64.32_{(8)} = ?_{(2)}$

6. $5164_{(8)} = ?_{(2)}$

7. $437.65_{(8)} = ?_{(2)}$

8. $.773_{(8)} = ?_{(2)}$

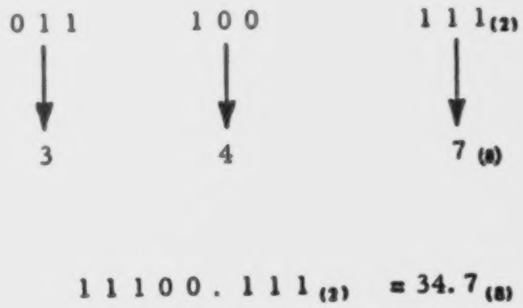

0 1 1
1 0 0
1 1 1(2)
3
4
7 (8)
1 1 1 0 0 . 1 1 1 (2) = 34. 7 (8)

Figure 9-14. Binary to octal conversion.

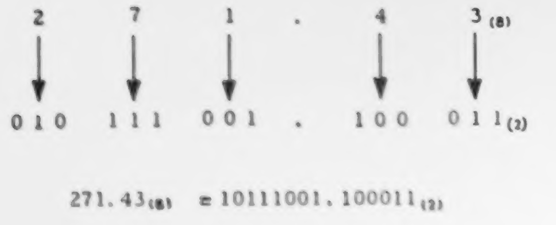


Figure 9–15. Octal to binary conversion.

504. Add and subtract octal numbers.

Octal Mathematical Operations. Mathematical operations in the octal system are similar to those in the decimal system. Since it is unlikely that you will need to multiply or divide octal numbers, we will discuss only addition and subtraction.

Octal addition. The sum and carry technique is used in octal addition as in any other system. You must make a carry whenever the sum equals or exceeds the base of the system. The carry isn't made until the whole column has been added. For instance, let's add the decimal numbers 27 + 18 + 19, as shown below:

$$\begin{array}{rl} 2 & \text{carry} \\ 27 & \\ 18 & \\ (+)\ 19 & \\ \hline 64 & \end{array}$$

You add the LSD column (7 + 8 + 9) and the sum equals 24. You carry the 2 to the next column and place the 4 in the answer. In effect, you divided the sum of the LSD column (24) by the base of the system (10). You then carried the quotient (2) and made the remainder (4) part of the sum.

This same process works well for octal addition. Just decimally add the LSD column, divide the sum by the base (8), carry the quotient, and make the remainder the LSD of the sum. Do the same to each additional column until all columns, including carriers, have been added. You will then have the octal sum of the octal numbers. To illustrate, let's add the octal numbers 47, 26, 75, and 24, as shown in the example below. Adding the LSD column as decimal numbers (7 + 6 + 5 + 4) gives a sum of 22. Dividing the sum (22) by 8 gives a quotient of 2 and a remainder of 6. The quotient (2) is carried to the next column, and the remainder (6) becomes the LSD of the answer. The next column, including the carry, adds up to 17. Dividing by 8 gives a quotient of 2 and a remainder of 1. The quotient is again carried to the next column, and the remainder becomes a digit in the answer. Since there were only two columns to be added, the final carry is brought down to become the MSD of the answer.

Example

$$\begin{array}{rl} 22 & \text{carries} \\ 47 & \\ 26 & \\ 75 & \\ +\ 24 & \\ \hline 216_{(8)} & \end{array}$$

Octal subtraction. Subtraction is again much the same in the octal system as it is with the decimal numbers. When a borrow is made in any system, the borrow is equal to the base of the system and the digit borrowed from is reduced by 1. Borrowing in octal subtraction, the borrow (8) is added decimally to the borrowing digit. The digit in the subtrahend is then subtracted decimally. In the example shown below, to subtract $45.4_{(8)}$ from $50.3_{(8)}$, The 4 in the subtrahend of column A is larger than the 3 in the minuend; therefore, a borrow must be made from the next higher order column containing a digit other than 0—in this case, column C. The 5 in column C is reduced to 4, and the borrow (8) is added to the 0 in column B. We now have 8 in column B, but the borrow must be transferred to column A; therefore, we reduce the 8 in column B to 7 and add 8 to the 3 in column A, which gives us 11. We now subtract the 4 in the subtrahend of column A from 11, and the difference (7) becomes the LSD of the answer. In column B, we now subtract 5 from 7 and get the next digit (2) of the answer. In column C, the subtrahend is now equal to the minuend, so the difference is zero.

Example:

Column	C	B		A
		7		
	4	8		11
Minuend	5	0	.	3
Subtrahend	4	5	.	4
		2	.	$7_{(8)}$

Exercises (504):

Solve the problems in their octal form, then check your answers by converting the numbers to decimal form and reworking the problems.

1. $\begin{array}{lr} & 563 \\ (+) & 214 \\ \hline \end{array}$

2. $\begin{array}{lr} & 471.21 \\ (+) & 73.65 \\ \hline \end{array}$

3. $\begin{array}{lr} & .4136 \\ (+) & .7435 \\ \hline \end{array}$

4. $\begin{array}{lr} & 664.12 \\ (+) & 37.47 \\ \hline \end{array}$

5. 3753
(+) 777

6. 7261
(−) 452

7. 4513.72
(−) 1372.36

8. 537.01
(−) 426.10

9. 3.1416
(−) 1.5708

10. 1.37765
(−) .24313

505. Convert numbers between the 8, 4, 2, 1 form and the decimal form.

Binary-Coded-Decimal (BCD) Codes. Since we have long used the decimal number system, we all tend to think decimally. Therefore, there are certain instances when it is easier and less error-productive to use decimal numbers, rather than octal or binary numbers, in computer readout and feed-in situations. For instance, let's say that a computer control panel has three rotary switches to select specific latitude information to be fed directly into the data memory. Switches 1, 2, and 3 might be used to select degrees, minutes, and seconds respectively. You can see that it would be difficult to interpret a switch position if the markings were in octal or binary form. Accordingly, the switches are marked by decimal numbers and the switch contacts arranged so that the switch output is in the binary-coded-decimal 8, 4, 2, 1 form.

The 8, 4, 2, 1 code. The 8, 4, 2, 1 code uses four binary bits to represent a decimal digit. You can convert a decimal number to and from the 8, 4, 2, 1 code in almost the identical way that you converted an octal number to binary form; that is, by inspection and direct substitution. The only difference is that you use four bits rather than three to represent the decimal digit. For instance, if the decimal number 512 is to be represented in 8, 4, 2, 1 code, the three groups of four binary bits are:

5 1 2
0101 0001 0010
$512_{(10)}$ = 010100010010 in 8, 4, 2, 1 code form

This code is called the 8, 4, 2, 1 code simply because of the powers of the positions of the four binary bits used to represent the decimal digit. Using the same logic, the binary equivalent of an octal number might be called a 4, 2, 1 code.

The 8, 4, 2, 1 code is very useful, but it has one big disadvantage: It is difficult to form the complements of numbers in this system. The easiest way for the computer to complement a number is to change 1s to 0s and 0s to 1s. Consider that decimal 2, coded in 8, 4, 2, 1 form, is 0010. The radix-minus-1 (9s) complement of decimal 2 is 7 (see objective 493). However, when 0010 is complemented, we get 1101 which in the 8, 4, 2, 1 code represents decimal 13, instead of 7. You can see that natural complementing doesn't work with the 8, 4, 2, 1 code. To overcome this disadvantage, the excess-three code was developed.

Exercises (505):

In problems 1, 2, and 3, convert the decimal numbers to 8, 4, 2, 1 form and problems 4, 5, and 6 to decimal form.

1. 732.

2. 643.

3. 9451.

4. 010110010111.

5. 001010010010.

6. 10000001.

506. Convert numbers between excess-three code and decimal form.

Excess-Three Code. This code is formed simply by adding 3 to each decimal digit and then substituting a group of four binary bits for each digit of the resultant decimal number, just as in the 8, 4, 2, 1 code. For example, to form the excess-three code of the decimal number 6, first add 3 to 6, yielding 9. Then, as in the 8, 4, 2, 1 code, substitute four binary bits for the 9. Therefore, $6_{(10)} = 1001_{(2)}$ in the excess-three code. To convert an excess-three coded number back to decimal form, merely substitute the proper decimal digit for each group of four binary bits and then subtract 3 from each digit.

5[illegible]4

Let's take the decimal number 426, form the excess-three code equivalent, complement the code, and convert back to decimal to see if we derive the 9s complement of 426:

	4	2	$6_{(10)}$	
(+)	3	3	3	
Equals	7	5	9	
Equals	0111	0101	1001	excess-three code
Complements	1000	1010	0110	
Equals	8	10	6	
Minus	3	3	3	
Equals	5	7	3	*= 9s complement* of $426_{(10)}$

You have seen how the excess-three code compensates for the disadvantage of the 8, 4, 2, 1 code. Both of these codes, however, share a characteristic that is inconvenient in certain circumstances. This undesirable trait is that, in changing the count represented by four binary bits, more than one bit can change value at the same time. For instance, increasing a count from 0000 to 0001 changes only the LSB, but changing from 0001 to 0010 changes both the LSB and the next bit. Again, necessity being the mother of invention, a code was developed to compensate for this drawback.

Exercises (506):

In problems 1, 2, and 3, convert the numbers to excess-three form and in 4, 5, and 6 to decimal form.

1. 27.

2. 493.

3. 784.

4. 10111100.

5. 010110111010.

6. 110001011100.

507. Convert numbers between gray code and pure binary forms.

The Gray Code. The gray code is not a true binary-coded-decimal code but rather a "cyclic" code. A cyclic code has the unique characteristic that only one bit changes value in proceeding from one number to the next successive number. This trait is used to advantage in couters and analog-to-digital conversion units in some computers. Binary numbers can be converted to gray code by applying the following rules as shown in figure 9-16.

(1) Make the MSB of the binary number the MSB of the gray code.

(2) Add the binary bits, laterally, from left to right, two at a time. Drop all carries.

(3) Make the sum of each two bits a bit in the gray code equivalent.

Figure 9-17 shows examples of converting a gray coded number to its binary form. The following rules are used to perform this conversion.

(1) Make the MSB of the gray code the MSB of the binary number.

(2) Add the second gray code bit to the first binary bit (MSB) and use the sum as the next binary bit. Drop any carry.

(3) Continue adding successive gray code bits to the preceding binary bits. The sum of the last addition is the LSB of the binary number.

Exercises (507):

In problems 1, 2, and 3, convert the gray coded numbers to pure binary form and in problems 4, 5 and 6, convert the binary numbers to gray code form.

1. 10110.

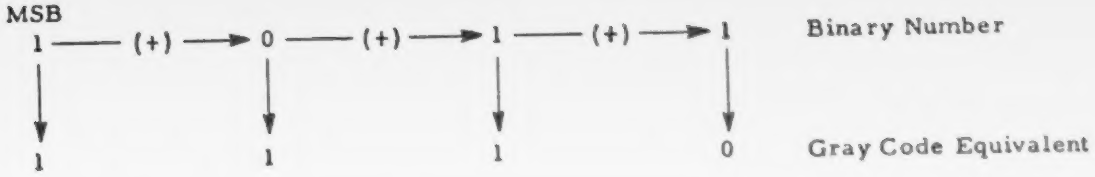
2. 10000.

3. 111011.

4. 10000.

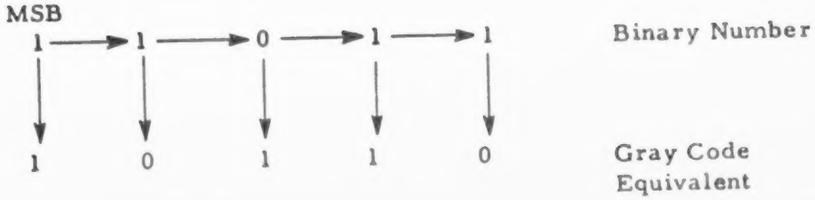
5. 11001.

6. 101100.


MSB
1 — (+) → 0 — (+) → 1 — (+) → 1
Binary Number
1 1 1 0
Gray Code Equivalent

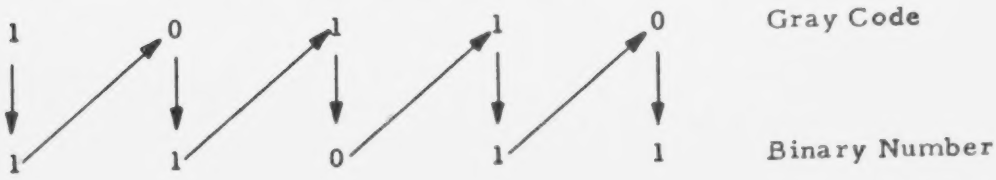
$1011_{(2)}$ = 1110 Gray Code

EXAMPLE 2.


MSB
1 → 1 → 0 → 1 → 1
Binary Number
1 0 1 1 0
Gray Code Equivalent

$11011_{(2)}$ = 10110 Gray Code

Figure 9–16. Examples of binary to gray code conversion.


1 0 1 1 0
Gray Code
1 1 0 1 1
Binary Number

1 0 1 1 0 Gray Code = $11011_{(2)}$

Figure 9–17. Gray code to binary conversion.

9-2. Logic Circuit Elements

The computer, like any complicated electronic device, is an aggregate of various individual components—diodes, resistors, transistors, etc. These comonents are combined to form logic elements. These logic elements, in turn, form functional units that can perform complicated logical operations. In this section, we will discuss the composition and function of logic gates, inverters, and flip-flops. These logic elements are the "building blocks" of the computer, and your knowledge is the "cement" that will tie them together to give you a troubleshooting and maintenance ability.

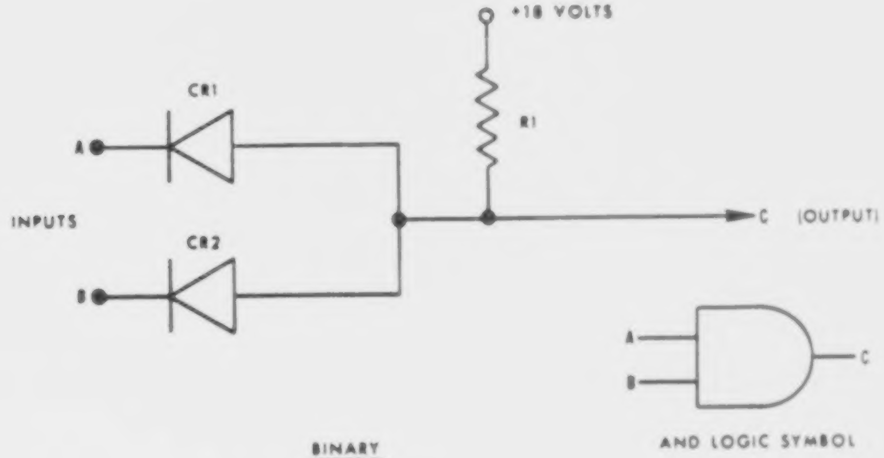
508. Given a logic diagram, identify the type logic used and calculate voltage readings from binary inputs and outputs and when components are shorted to ground.

Logic Elements. As you know, the binary 1s and 0s we have been discussing can be represented by signals. In most computers, a binary 1 is represented by a more positive voltage or a positive pulse, and binary 0 is represented by a negative voltage or no pulse. This type of representation of binary 1 and 0 is called positive logic. Though 1 and 0 may both be represented by a negative voltage, such as -.75 volt and -1.15 volts, respectively, this is still positive logic because the 1 is represented by a voltage positive with respect to the voltage representing 0. Negative logic, where the voltage representing 1 is negative with respect to that representing 0, is used in some computer applications. The logic elements we will discuss have the same functions regardless of the type of logic, so we will primarily use positive logic in our discussion.

AND-Gates. A gate is essentially a switch that has two or more inputs, and allows information to flow when certain combinations of input signals are present. AND-gates produce a binary 1 output only when 1s are present at all inputs. When 1s are not present at all inputs, the output will be a binary 0. Of course, when we speak of 1s and 0s, we mean the voltage representing these binary values. Different types of components can be used for AND-gates (relays, tubes, transistors, etc.), but since diodes are used in most AND-gates with which you will be concerned, we will discuss this type.

Figure 9-18 shows a positive (because it is designed for positive logic) diode AND-gate, the logic symbol associated with it, and the outputs (C) for the four possible combinations of inputs (A and B). This table of inputs and outputs is called a truth table. In figure 9-18 we have arbitrarily selected the logic levels of 6 volts and 0 volts to represent 1 and 0 respectively. The polarity and level of AND-gate (and OR-gate) outputs are generally the same as the inputs. That is, if a 1 going in is 6 volts, a 1 coming out will be 6 volts.

Let's apply the input combinations in figure 9-18 to the AND-gate and see how the gate develops its output. With binary 0s (0 volts) applied to both CR1 and CR2, both diodes conduct equally, connecting the applied 0 volts to the output. Thus, with both inputs 0, the output is 0. In the second combination, A = 0 and B = 1 (0 volts and +6 volts respectively), the potential difference between CR1 and the



BINARY

INPUTS A	INPUTS B	OUTPUT C
0	0	0
0	1	0
1	1	1
1	0	0

1 = 6 VOLTS
0 = 0 VOLTS

AND TRUTH TABLE

Figure 9–18. AND-gate.

bias voltage (+18 volts) is greater than the potential between CR2 and the bias; therefore,, CR1 conducts heavily. Its output side drops to 0 volts, back biasing CR2 and leaving the output a binary 0 (zero volts). The third combination places 6 volts at both inputs; both diodes conduct equally, in effect connecting the 6 volts to the output. Thus, all 1s in cause a 1 output. The fourth input combination is just the reverse of the second combination. The binary 0 at CR2 causes CR2 to conduct heavier than CR1. The output side of CR2 drops to 0 volts, back biasing CR1, and the output is 0 (0 volts). Now, looking at the outputs for the four possible combinations of inputs, we see that the only time the output is 1 is when both inputs are 1. Thus, we can make this statement: Any 0 input to an AND-gate will force a 0 out. This holds true for any number of inputs and for any type of AND-gate.

Exercises (508):

1. State the type of logic used in figure 9-19 and explain your answer.

2. What voltage would be read at TP1 in figure 9-19 if the inputs of CR1, CR2, and CR4 were binary 0s and the input to CR3 a binary 1? Explain your answer.

3. How would the operation, and therefore the output, of the circuit in figure 9-19 be affected if the input side of CR2 were shorted to chassis ground (0 volts)?

509. Given logic diagrams, identify the types of logic used and calculate binary and voltage outputs of the circuit.

OR-Gates. The OR-gate will produce a 1 at the output whenever one or more inputss are 1. As is true in an AND-gate, different types of components can form an OR-gate, but we will use a diode gate in our illustration.

Figure 9-20 shows a positive diode OR-gate, its logic symbol, and its truth table. Again, we use the logic levels of 6 volts and 0 volts. Applying the first combination of inputs, the 0 volts at both inputs A and B cause CR1 and CR2 to conduct equally, and they effectively connect the 0-volt input to the output. In the second combination, the 6 volts at input B makes CR2 conduct heavier than CR1 because of the greater potential difference. The output side of CR2 goes to 6 volts, back biases CR1, and makes the output 6 volts. The third combination finds both inputs at 6 volts (1), causing both diodes to conduct equally and, in effect, short the 6 volts input to the output. The last combination is the reverse of the second combination. Here, the 1 at input A causes CR1 to conduct heavily, back biasing CR2, and in effect connecting the 6 volts to the output. We have found that a 1 at either input causes a 1 to appear at the output. Any 1 in to an OR-gate forces a 1 out. Again, this holds true no matter what type of OR-gate is used or how many inputs the gate has.

In our discussion of the AND- and OR-gates, we have called them positive gates because of the type of logic we used with them. Look again at the AND-gate in figure 9-18 and mentally reverse the logic levels shown there, so that 0 volts = 1 and 6 volts = 0. If we apply the same four possible combinations of input 1s and 0s as shown, we will come up with these outputs.

Binary	
Inputs	*Outputs*
A B	C
0 0	0
0 1	1
1 1	1
1 0	1

Now compare these outputs with the outputs for the positive OR-gate shown in figure 9-20. They are identical. If we applied negative logic to the positive OR-gate of figure 9-20, we sould get outputs identical to those of the positve AND-gate of figure 9-18. A positive AND-gate can operate as a negative OR-gate, and a positive OR-gate can operate as a negative AND-gate. Remember that positive and negative as used here refer to the type of logic used in the circuit.

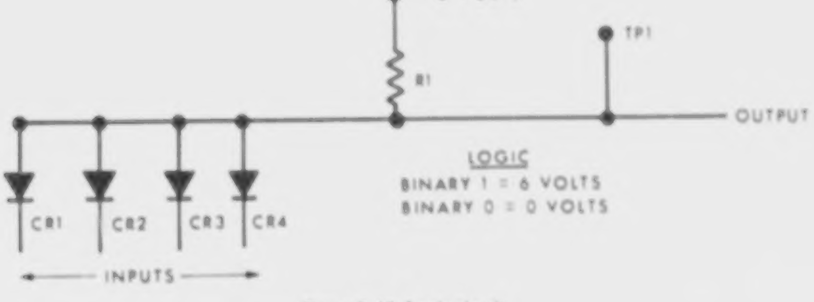
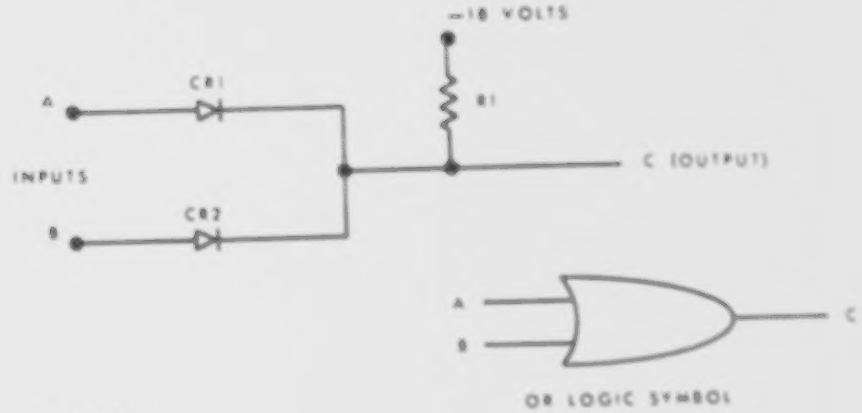


Figure 9–19. Logic circuit.



BINARY

INPUTS		OUTPUT
A	B	C
0	0	0
0	1	1
1	1	1
1	0	1

OR TRUTH TABLE

1 = 6 VOLTS
0 = 0 VOLTS

Figure 9-20. OR-gate.

Inverters. An inverter is a device whose output is opposite in polarity to its input. Figure 9-21 shows a representative negative-positive-negative (N–P–N) transistor positive logic inverter, the output (A) for the two possible input conditions (A), and the logic symbol associated with the inverter. The bar (¯) above the A in the output column indicates not. In effect, the output is not the input, which is appropriate, since an inverter output is of opposite polarity to its input. A, then, is read as not A. Again, we have chosen positive logic levels 6 volts and 0 volts.

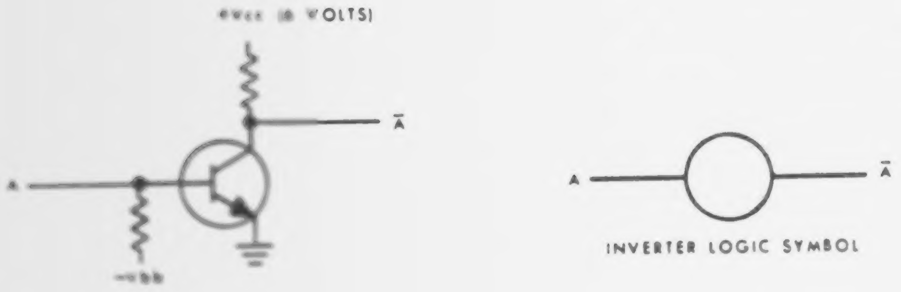
Since the transistor shown in figure 9-21 is an N–P–N transistor, it will be turned on when its base is positive with respect to its emitter. If we apply 6 volts (binary 1) to the input, the base becomes positive with respect to the emitter; the transistor turns on and, in effect, completes a ground through the emitter and collector to the output. When 0 volts (binary 0) are applied to the base, the transistor turns off, and the collector (and output) voltage will revert to the binary 1 level because of the positive V_{CC}. By using a positive-negative-positive (P–N–P) transistor and applying the proper bias voltages, an inverter can also operate with negative logic.

The NOR-Gate. NOR is a contraction of NOT OR. The NOR function is performed by an OR-gate whose output is inverted. A NDR-gate produces a 1 output whenever all inputs are 0 and produced a 0 output whenever any input is 1.

Figure 9-22 shows a representative diode-transistor, 2-input positive-logic NOR-gate; a logic symbol often associated with it; and the NOR truth table. If you inspect this circuit carefully, you will see that it is a combination of the OR-gate shown in figure 9-20 and the inverter shown in figure 9-21. As the four possible input combinations are applied to the input diodes CR1 and CR2 in figure 9-22, the signal at the junction of the diodes and R1 will be exactly as the outputs shown for the OR-gate in figure 9-20; that is, 0, 1, 1, and 1 for the first through the fourth input combinations respectively. These signals are then applied through R1 in figure 9-22 to the inverter transistor and inverted.

Looking at the NOR truth table output column, we see that any binary 1 in forces a binary 0 out. This applies to any NOR-gage regardless of the number of inputs. As is true of the other gates we have discussed, a NOR-gate can be made to operate with negative logic by changing the type of components and applying the proper bias voltage.

The NAND-Gate. NAND is a contraction of NOT AND. The NAND function can be performed by an AND-gate whose output is inverted. This gate will produce a 1 output whenever any input is 0 and a 0 output whenever all inputs are 1. Figure 9-23 shows a representative diode-transistor, positive-logic NAND-gate; a logic symbol often used with it; and the NAND truth table. As you can see, the NAND-gate is a combination of the AND-gate shown in figure 9-18 and the inverter shown in figure 9-21. As the four possible combinations of inputs are applied to the input diodes CR1 and CR2 in figure 9-23, the signal at the junction of the diode and R1 will be exactly as the outputs shown for the AND-gate of figure 9-18, that is 0, 0, 1, and 0 for the first through the combinations. These signals are then applied through R1, in figure 9-23, to the inverter transistor, and



+Vcc (6 VOLTS)
$\bar{A}$
A
−Vbb
A
$\bar{A}$
INVERTER LOGIC SYMBOL

BINARY

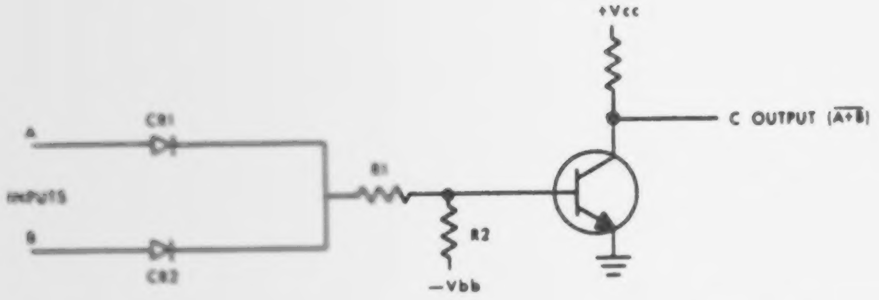
INPUT (A)	OUTPUT ($\bar{A}$)
1	0
0	1

1 = 6 VOLTS

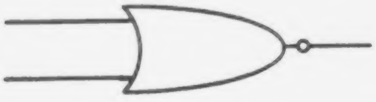
0 = 0 VOLTS

INVERTER TRUTH TABLE

Figure 9–21. Inverter.



+Vcc
C OUTPUT ($\overline{A+B}$)
A
CR1
INPUTS
R1
B
CR2
R2
−Vbb



NOR LOGIC SYMBOL

BINARY

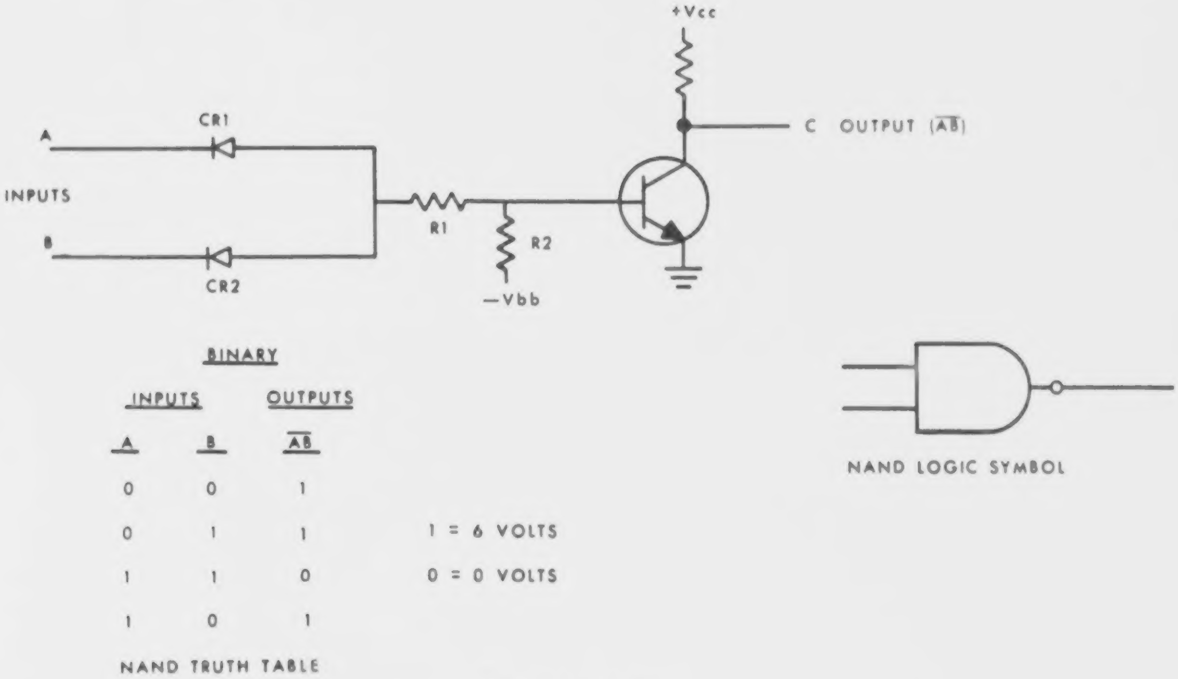
INPUTS		OUTPUT
A	B	$\overline{A+B}$
0	0	1
0	1	0
1	1	0
1	0	0

1 = 6 VOLTS

0 = 0 VOLTS

NOR TRUTH TABLE

Figure 9–22. NOR-gate.


+Vcc
C OUTPUT ($\overline{AB}$)
A
CR1
INPUTS
B
CR2
R1
R2
−Vbb
NAND LOGIC SYMBOL

BINARY

INPUTS		OUTPUTS
A	B	$\overline{AB}$
0	0	1
0	1	1
1	1	0
1	0	1

NAND TRUTH TABLE

1 = 6 VOLTS

0 = 0 VOLTS

Figure 9–23. NAND-gate.

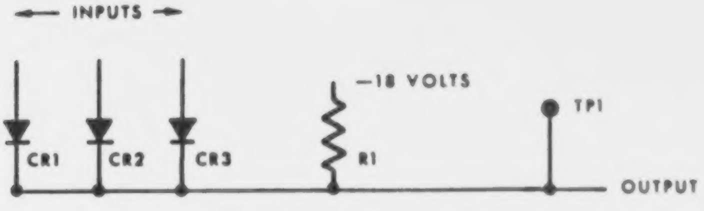
inverted. Looking at the NAND truth table in figure 9-23 we see that the output AB is a 1 when any input is a 0 and a 0 when both inputs are 1. As is true of the other gates we have discussed, the NAND-gate can be made to operate with negative logic by using the proper components and bias voltages.

Exercises (509):

1. What type of gate is shown in figure 9-24?

2. What voltage would be read at TP1 of figure 9-24 if the inputs to CR1 and CR2 were binary 1s and the input to CR3 was binary 0?

3. How could the gate in figure 9-24 be made to operate as a negative AND-gate?


← INPUTS →
CR1
CR2
CR3
−18 VOLTS
R1
TP1
OUTPUT

LOGIC

BINARY 1 = 6 VOLTS

BINARY 0 = 0 VOLTS

Figure 9–24. Logic circuit.

4. What type of circuit do CR1, CR2, and CR3 in figure 9-25 constitute?

5. With 6 volts applied at inputs 5 and 6 in figure 9-25, what binary value will be represented at TP2?

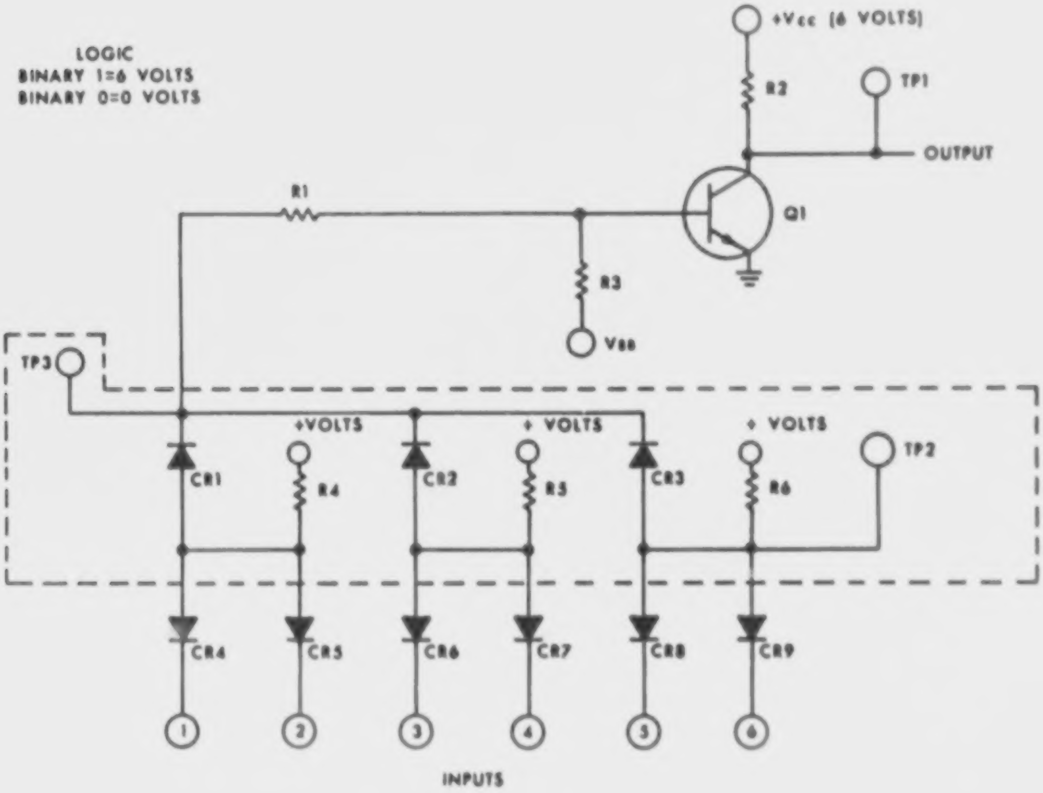

LOGIC
BINARY 1=6 VOLTS
BINARY 0=0 VOLTS
+Vcc (6 VOLTS)
R2
TP1
OUTPUT
R1
Q1
R3
VBB
TP3
+VOLTS
+ VOLTS
+ VOLTS
TP2
CR1
R4
CR2
R5
CR3
R6
CR4
CR5
CR6
CR7
CR8
CR9
1
2
3
4
5
6
INPUTS

Figure 9–25. Logic circuit.

6. Explain how a binary 0 could be developed at TP1 in figure 9-25.

7. Assume these conditions in figure 9-25:
   All inputs = binary 0
   TP3 = 0 volts
   TP1 = 0 volts

   If the output is correct, explain why. If the output is not correct, give possible causes of the incorrect output.

8. If all of the components within the dotted line were removed from the circuit in figure 9-25 and the output side of diodes CR4–9 were tied together and fed through R1 to the base of Q1, what type of circuit would this then be?

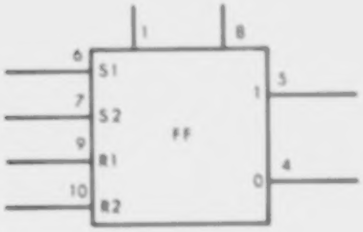
510. Define bistable and monostable flip-flops and interpret a multivibrator diagram to state time intervals, width, and shape of signals.

Flip-Flops. You should already be acquainted with the internal workings of multivibrators (flip-flops) from previous training. Because of this we will discuss flip-flops as complete units. We will determine what outputs will be developed for specified inputs rather than how the outputs are developed. There are essentially three basic types of flip-flops: astable, bistable, and monostable (single-shot).

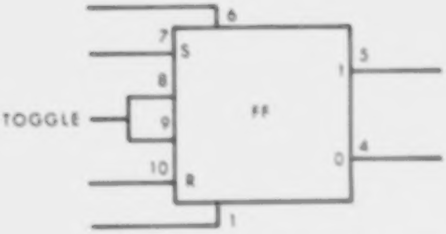
The astable flip-flop. Astable (having no stable state) implies that the output of this type of flip-flop will continuously alternate. Therefore, an astable circuit may be regarded as a generator, producing an output that varies at a rate determined by the design of the circuit. Astable flip-flops can be designed to produce negative or positive pulses of various pulse widths. Since an astable flip-flop produces a square wave output pulse at a specified rate, it is used in computer interval timing and control circuitry to generate clock pulses.

The bistable flip-flop. Compared to the astable flip-flop, which we called a generator, the bistable flip-flop, stable in either of two states, is more a storage device. Each bistable flip-flop can store one bit (1 or 0) of information. You should be familiar with two types of bistable flip-flops, the basic flip-flop, and the complementing flip-flop. Figure 9-26 shows logic symbols that are frequently used with these flip-flops.

The basic flip-flop has essentially two inputs and two outputs: The SET and RESET inputs and the SET and RESET outputs. In the basic flip-flop, shown in figure 9-26, pins 6 and 7 are SET inputs and are marked S1 and S2. These inputs are in parallel, so, in effect, a signal at either pin is a SET input. Pins 9 and 10, marked R1 and R2, are also in parallel with each other, so an input on either pin is a RESET input. Pins 9 and 10, marked R1 and R2, are also in parallel with S1 and S2. The outputs, at the right side of the logic symbol, are marked 1 and 0. The 1 indicates the SET output and the 0, the RESET output. In a logic diagram, only those pins that are used will be shown. Occasionally, the outputs will not be marked 1 and 0. If they are not, the output opposite the SET input is the SET output. In both the bistable and complementing flip-flops, the binary value (1 or 0) represented at the SET output is considered to be the stored content of the flip-flop. That is, if the SET output is 0, the flip-flop is storing a 0, and if the SET output is 1 the flip-flop is storing a 1.



BASIC FLIP—FLOP



COMPLEMENTING FLIP—FLOP

Figure 9-26. Bistable flip-flop logic symbols.

A basic flip-flop is said to be SET (in the SET state) when the SET output is 1 and RESET (in the RESET state) when the RESET output is 1. Due to the nature of the flip-flop, if one output is 1, the other output will be 0, as shown below:

SET
Set output = 1
Reset output = 0

RESET
Set output = 0
Reset output = 1

A 1 applied to any SET input will SET the flip-flop. It will stay SET until a 1 is applied to a RESET input. Of course, if the flip-flop is already SET, a 1 applied to a SET input will not change the state. It takes a 1 applied to the input opposite to that state it is already in to change the state of this flip-flop. Even then, the flip-flop will change state only when the input signal goes from a 0 to a 1 level. That is, the mere presence of a 1 level will not change the state; it takes a change from 0 to a 1 level at the proper point.

Let's assume that the basic flip-flop in figure 9-26 is presently SET (SET output = 1 and RESET output = 0) and that all input signals are 0. Now, if we apply a 1 level to either RESET input, the flip-flop will change state; the SET output will become 0, and the RESET output will become 1. How long will it stay that way? Until we apply a 1 to a SET input! Remember, it takes a change from a 0 level to a 1 level to the proper input to change states.

The "complementing" flip-flop shown in figure 9-26 has the same capabilities as the basic flip-flop (both types can be used in counter and storage registers) plus some features uniquely its own. The outstanding feature of the complementing flip-flop is that it can be changed to the complement of its previous state by simultaneously applying a 1 level to the SET-RESET inputs, pins 8 and 9. Before we discuss this further, let's examine two other inputs. Pins 6 and 1 are SET and RESET inputs respectively. They operate the same as the SET and RESET inputs of the basic flip-flop and have the same effect on the outputs, which are also like those in the basic flip-flop. Now back to pins 8 and 9. This SET-RESET input is commonly called a toggle input because, in effect, it acts like a toggle switch turning the flip-flop on and off. This input will usually be a series of 1-level pulses, at a fixed repetition rate, which cause the flip-flop to alternately SET and RESET. For instance, if the flip-flop is SET (SET output = 1) and a 1-level pulse appears at the toggle input, the flip-flop will RESET. After a time determined by the width of the toggle pulse, the toggle input will revert to a 0 level. Since this is a bistable flip-flop, it will stay RESET until the next 1 level is applied. Now, because of the construction of this flip-flop, when the next 1-level pulse appears at the toggle input, the flip-flop will toggle to the SET state and will stay SET until the next toggle pulse forces it to RESET. Of course, there is always an exception, which brings us to the two remaining inputs, pins 7 and 10.

Pins 7 and 10 are used as "inhibit" inputs to the SET and RESET sides respectively. A 1 level is an inhibiting level, and a 0 level is an enabling level. An inhibit level prevents a toggle pulse from causing the flip-flop to go into the inhibited state but not out of the inhibited state. For instance, if the complementing flip-flop in figure 9-26 is SET, and the SET side is inhibited (a 1 at pin 7), a toggle pulse will cause the flip-flop to RESET, but succeeding pulses cannot cause it to SET so long as the inhibit level is present at pin 7. Likewise, a 1 level at pin 10 would keep the flip-flop from going to the RESET state but not from the RESET state. Generally, an inhibit level will be present at only one of the inputs. Naturally, if both sides were inhibited, the flip-flop could not change states when a toggle pulse was applied. Notice that we have talked about the effect of the inhibit inputs as referenced to the toggle unit. This is because the inhibit inputs have no effect on the "normal" SET and RESET inputs, pins 6 and 1 respectively. Due to the internal construction of this flip-flop, a 1 level at either of these inputs will override any inhibit level present. One last item about the inhibit inputs. These inputs can cause the flip-flop to SET or RESET when they first appear. Therefore, the inhibit levels are generally applied when the flip-flop is in the state that is to be inhibited. That is, if a 1 level were to be applied to pin 7 to inhibit the SET side, this level would usually be applied only when the flip-flop is already SET. Inhibit inputs are not generally used to change the state of the flip-flop.

Figure 9-27 is a timing chart of a 1200-nanosecond cycle of possible inputs to the complementing flip-flop shown in figure 9-26. Using the information you have just studied, plot the SET and RESET outputs which would be derived from these inputs. After you have plotted the outputs, see if your plots agree with those shown in figure 9-28. The SET output plot was derived as follows: At time zero, a positive pulse appears at pin 1 in figure 9-27 and RESETS the flip-flop. (In this instance, we assume that pin 1 was at a 0 level before time zero.) We know that the flip-flop will stay RESET (SET output = 0) until a positve going pulse at the toggle input or at pin 6 forces it to go SET. Since pin 6 is not plotted, we can assume that it will be at 0 level and will have no effect on the flip-flop. Therefore, only the toggle input will cause a change of state. Remembering that it takes a change from 0 to 1 to change states, the SET output will remain at 0 for at least 200 ns, at which time the first toggle pulse appears. Since pin 7 is at the enabling level (0) at this point, the flip-flop will SET as the change from 0 to 1 occurs at the toggle input, that is, at 200 ns. Though the toggle input reverts to 0 at 300 ns, the flip flop will stay SET (SET output = 1) until the next 1 level appears at the toggle input at 400 ns. In the meantime, at 300 ns, an inhibit level appears at pin 7. The flip-flop is already SET, so this level has no immediate effect on the flip-flop. Now, at 400 ns, a toggle pulse appears and tries to change the flip-flop state. The enabling level at pin 10 allows the flip-flop to RESET, and it will stay in this state at least until the next toggle

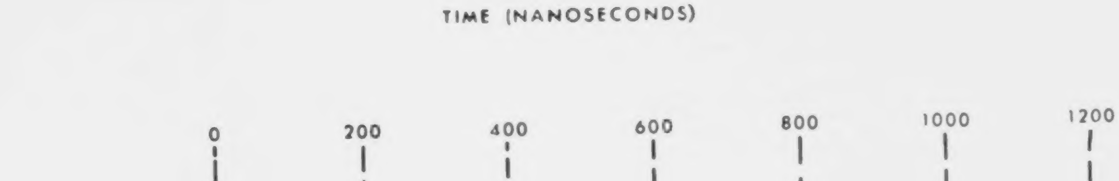


Figure 9–27. Complementing flip-flop input plot.

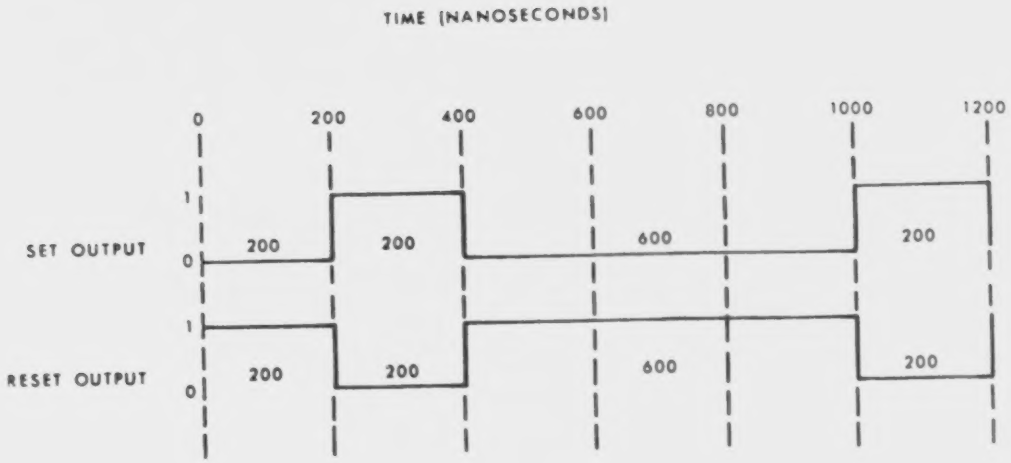
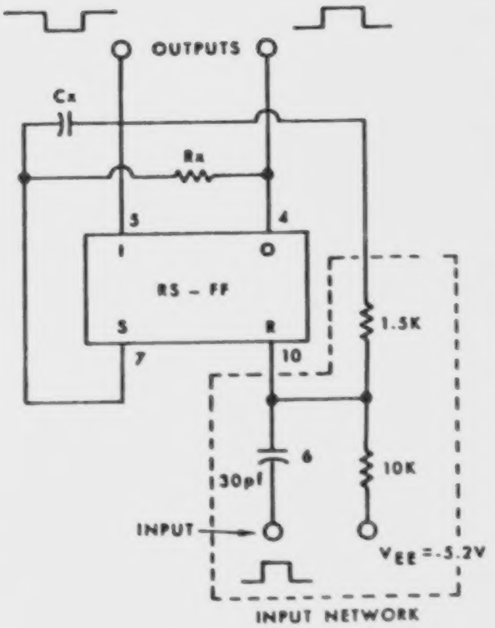


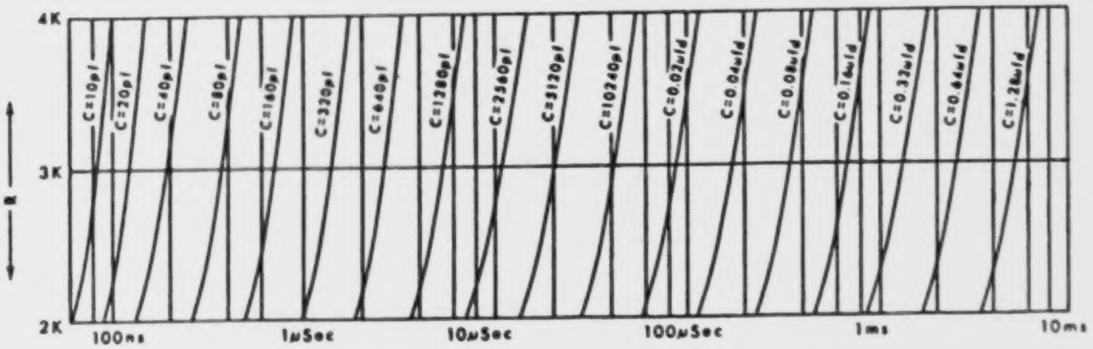
Figure 9–28. Complementing flip-flop output plot.

pulse. At 500 ns, an inhibit level appears at pin 10. Since the flip-flop is already reset during the entire time that this level is present, it has no effect on the flip-flop. At 600 ns, the next toggle pulse appears and tries to SET the flip-flop but, because of the inhibit level at pin 7, the flip-flop can't SET and must remain RESET at least until the next toggle pulse, which occurs at 800 ns. However, at 800 ns, the inhibit level is still present at pin 7 and the flip-flop remains RESET. At 900 ns, the inhibit level disappears so the next toggle pulse, at 1000 ns, SETS the flip-flop and it remains in this state for the rest of the 1200-ns cycle. This finishes the plot of the SET output in figure 9-28. The RESET output is just the inverse of the SET output, because if one output is 1 the other is 0, and vice versa.

The monostable (single-shot) flip-flop. Figure 9-29,A, shows a single-shot flip-flop composed of a basic flip-flop and an external pulse-shaping network consisting of Rx and Cx. When the flip-flop is triggered by a positive pulse at the RESET input, a 0 will be obtained at the SET output. The flip-flop will stay RESET for a period of time determined by the values of Rx and Cx and will then automatically SET. Though the arrangement shown is for a flip-flop stable in the SET state, it could be made stable in the RESET state by rearranging the input and pulse-shaping connections. Figure 9-29, shows a chart which can be used for determining output pulse length for given values of Rx and Cx. For instance, if Rx = 3kΩ and Cx = 10 picofarads (pico = one-trillionth), then the output pulse length will be a 50 nanoseconds.


OUTPUTS
Cx
Rx
5
4
1
0
RS - FF
S
R
7
10
1.5K
6
30pf
10K
INPUT
VEE = -5.2V
INPUT NETWORK

A



OUTPUT PULSE LENGTH AS A FUNCTION OF R AND C
TIMES ARE PREDICTED BY FORMULA $T_{out} = 20ns + 1.4R(C+5pf)$

B

Figure 9–29. Single shot flip-flop logic symbol.

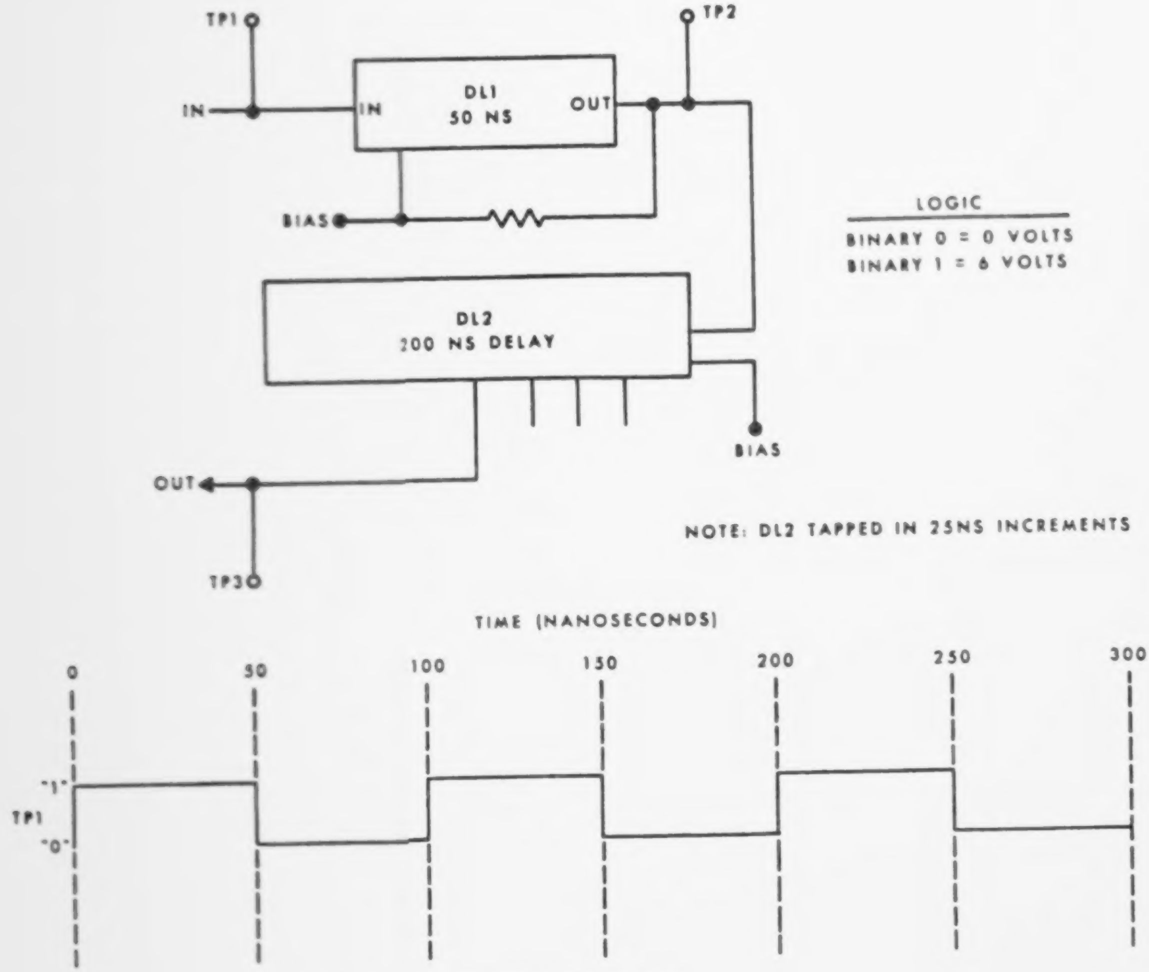

TP1
TP2
IN
IN
DL1
50 NS
OUT
BIAS
LOGIC
BINARY 0 = 0 VOLTS
BINARY 1 = 6 VOLTS
DL2
200 NS DELAY
BIAS
OUT
TP3
NOTE: DL2 TAPPED IN 25NS INCREMENTS
TIME (NANOSECONDS)
0
50
100
150
200
250
300
"1"
TP1
"0"

Figure 9–30. Flip-flop timing.

Exercises (510):

1. What will be the width of the positive pulses read at TP2 of figure 9-30?

2. What will be the interval between the first and second positive pulses felt at TP3 of figure 9-30?

3. Which type of flip-flop would be used to generate a square wave to be used for timing purposes?

4. Define the terms "bistable" and "monostable" as applied to flip-flops.

5. What are the major advantages of using one-piece, integrated microcircuits in computers, rather than conventional solid-state circuits?

ANSWERS FOR EXERCISES

CHAPTER 1

Reference:

400 – 1. Any material that has many free electrons.
400 – 2. A force is applied to the random movement of free electrons in the conductor to cause the electrons to move generally in the same direction.
400 – 3. Negative to positive.
400 – 4. a. Positive 9.
    b. Zero.
    c. Positive 14.
    d. Negative 4.
    e. Negative 1.
    f. Positive 3.
400 – 5. I.
400 – 6. E.

401 – 1. Ohm.
401 – 2. Its length.
401 – 3. Ω.
401 – 4. Cross-sectional area.
401 – 5. Opposition to current flow.
401 – 6. Compare your drawings to figure 1-4 for answer.

402 – 1. a. 3,600,000 ± 180,000.
    b. 2,300 ± 460.
    c. 980,000 ± 98,000.
    d. .1 ± .005.
    e. 7,700,000 ± 1,540,000.
    f. 2.2 ± .22.
    g. 47 ± 9.4.
402 – 2. a. Red-green-red.
    b. Blue-black-gold.
    c. Brown-orange-yellow-silver.
    d. Brown-black-black-gold.
    e. Violet-yellow-orange.

403 – 1. An EMF source, a conductor, and a resistor or other power dissipating devices (bell, lamp, etc.).
403 – 2. Refer to figure 1-7 to check your answers.

404 – 1. The number to be multiplied by itself. In powers of 10, the base number is 10.
404 – 2. The power of a number. The number of times a base number is multipled by itself.
404 – 3. The number proceeding the base number and exponent.
404 – 4. a. 2×10^3.
    b. 1.58342×10^5.
    c. 1.8×10^4.
    d. 1.791×10^{-1}.
404 – 5. a. 1.30312×10^{12}.
    b. 8.37×10^{10}.
    c. 4.14×10^{-10}.
    d. 1.876×10^7.
404 – 6. 7×10^2.
404 – 7. 3.6×10^7.
404 – 8. 2.1×10^3.

405 – 1. a. 3KΩ.
    b. 60,000V.
    c. .002 amps.
    d. 600 mA.
    e. .00015 kW.
    f. 10,000,000 ohms.
    g. 5,000,000 μ amps.
    h. .1K ohms.
    i. .000002 amps.

406 – 1. An equation is a mathematical statement that two quantities are equal.
406 – 2. An axiom is a truth or a tact that is self-evident and needs no proof.

407 – 1. a. X = 8.
    b. X = 6.
    c. X = 5.
    d. X = 7.
    e. X = 12.
    f. X = -3.
    g. X = -5.
    h. X = 5.
    i. X = 9.
    j. X = 7.
    k. X = 12.
    l. X = 13.
407 – 2. Cross multiply to get AD = BC.
407 – 3. 100 milliamps (.1 amp).

408 – 1. That property of a material which enables it to attract pieces of iron.
408 – 2. Natural and artifical.
408 – 3. Permanent and temporary.
408 – 4. A material's opposition to the magnetic lines of force.
408 – 5. The amount of magnetism that remains in a temporary magnet.
408 – 6. The material's ability to retain residual magnetism.
408 – 7. The ease with which magnetic lines of force distribute themselves throughout the material.
408 – 8. Poles of the magnet.
408 – 9. They are encased in a soft iron case called a magnetic screen or shield.
408 – 10. Severe jarring or high temperature.

409 – 1. An electrically excited magnet capable of exerting mechanical force.
409 – 2. A bar magnet.
409 – 3. An electromagnet.
409 – 4. Any further increase will not produce an appreciable increase in lines of flux about the coil.
409 – 5. When you place a bar of iron or soft steel in an energized coil with electron flow through it, the bar is pulled through the coil by the field strength of the coil until the bar's center is near the center of the coil, where the field is most intense.

410 – 1. When current flows in the coil, electromagnetism pulls the moveable bar toward the core. The movement of the bar opens or closes a circuit.
410 – 2. A single pole, double-throw (SPDT) relay.
410 – 3. Deenergized.
410 – 4. A vibrator.
410 – 5. Overload relay.
410 – 6. Relay burnishing tool.
410 – 7. The relay could chatter, hum, or have reduced magnetic pulling power.
410 – 8. An open coil.
410 – 9. Check its resistance with an ohmmeter and compare the measured reading against the manufacturer's specified value.

CHAPTER 2

411 – 1. A source of power (battery), a load device (resistor), a conductor (wire), a safety device (fuse), and a control device (switch).
411 – 2. a. $E_a = 220V$.
    b. $E_1 = 150V$.
    c. $I_1 = 2A$.
    d. $E_3 = 40V$.

e. $I_2 = 2A$.
f. $E_3 = 20V$.
g. $I_3 = 2A$.
h. $E_4 = 10V$.
i. $I_4 = 2A$.

411 – 3. The algebraic sum of the currents at any junction of conductors is zero. This means that the sum of all currents flowing to a point must be equal to the sum of currents flowing away from that point.

411 – 4. The algebraic sum of the applied voltage and the voltage drops around any closed circuit is zero. (The applied voltage is equal to the sum of the voltage drops around the circuit.)

412 – 1. a. $I_T = 1A$.
b. $R_T = 100\Omega$.
c. $P_T = 100W$.
d. $E_1 = 40V$.
e. $I_1 = 1A$.
f. $P_1 = 40W$.
g. $E_2 = 30V$.
h. $I_2 = 1A$.
i. $P_2 = 30W$.
j. $E_3 = 20V$.
k. $I_3 = 1A$.
l. $P_3 = 20W$.
m. $E_4 = 10V$.
n. $I_4 = 1A$.
o. $P_4 = 10W$.

413 – 1. To provide from a single power source voltage values other than the source voltage.
413 – 2. A reference point or the metal chassis.
413 – 3. Negative.
413 – 4. Six.

414 – 1. To vary current.
414 – 2. Two.
414 – 3. Three.
414 – 4. To vary voltage.

415 – 1. a. $E_a = 6V$.
b. $I_T = .48A$.
c. $R_T = 12.5\Omega$.
d. $P_T = 2.9W$.

416 – 1. A resistor in one of the branches has become open. Total circuit resistance has increased, causing the drop in current.
416 – 2. Zero.
416 – 3. To prevent shunt or parallel loads from affecting the resistance reading.
416 – 4. Total circuit current would increase greatly.

417 – 1. a. $E_a = 3V$.
b. $R_T = 70K\Omega$.
c. $I_T = .5mA$.
d. $P_T = 17.5\ mW$.

418 – 1. Current will cease to flow.
418 – 2. Current will increase.
418 – 3. It will decrease.
418 – 4. It is decreased.
418 – 5. The voltmeter will read a portion of the applied voltage (the voltage dropped by the series resistor).
418 – 6. Disconnect the power source from the circuit.
418 – 7. Zero.

419 – 1. A voltage divider that has been loaded with an electronic component or circuit which draws current from the source.
419 – 2. There are two.
419 – 3. Current.
419 – 4. Zero.
419 – 5. Total circuit resistance decreases, total circuit current increases, and the voltage drop across the series resistor increases.
419 – 6. a. $E_a = 125V$.
b. $I_T = 5mA$.
c. $R_T = 25\Omega$.
d. $E_A = 125V$.
e. $I_5 = 2.5mA$.
f. $E_B = 62.5V$.
g. $I_4 = 1.25mA$.
h. $E_c = 31.25V$.
i. $I_3 = .625mA$.
j. $E_D = 15.625V$.
k. $I_2 = .3125mA$.
l. $I_1 = .325mA$.

420 – 1. No difference in potential would exist between points A and B; no current would flow through the galvanometer.
420 – 2. The current will increase.
420 – 3. A 2-ohm resistor.

CHAPTER 3

421 – 1. a. $E_{pk} = 100V$.
b. $E_{eff} = 70.7V$.
c. $E_{ave} = 63.6V$.
421 – 2. a. $E_{pk} = 155.5V$.
b. $E_{ave} = 99V$.

422 – 1. a. Kilohertz designates thousand cycles per second.
b. Megahertz designates million cycles per second.
c. Millihertz designates of one cycle in one thousandth of a second.
d. Microhertz designates one cycle in one millionth of a second.
422 – 2. When voltage and current of a waveform are not moving simultaneously, we say that the voltage and current are out of phase.

423 – 1. A conductor, a magnetic field, and motion.

424 – 1. The current will alternate.
424 – 2. The magnitude of the induced current is maximum.

425 – 1. The strength of the magnetic field, the number of conductors, and the speed of rotation of the conductors.
425 – 2. The AC output increases because we are cutting more lines of force.

426 – 1. Pole pieces, sliprings and brushes, field coil, armature and an external load.
426 – 2. a. The pole pieces provide a path for the magnetic lines of forces.
b. The rotating conductor is the winding on the armature core as it is rotated through a magnetic field, cutting magnetic lines of force. This action induces a voltage in the rotating conductor.
c. Slip rings provide a method of transferring the induced current from the rotating conductor to a stationary external circuit.
d. The external circuit or load provides a path in which the induced current flows so that useful work can be done.

427 – 1. The DC generator uses a commutator instead of sliprings.
427 – 2. Pole pieces, armature (rotating conductor), commutator, and brushes.

428 – 1. Zero.
428 – 2. The output is a rippling DC.

429 – 1. The rheostat regulates the field which, in turn, controls the generator output.
429 – 2. There are two paths for current flow. Part of the current flows through the field and part flows through the load.
429 – 3. A compound generator because it combines the characteristics of both the series and shunt generators.

430 – 1. Stationary windings provide a rotating magnetic field and the magnet (rotor) follows this field as it rotates through 360°.
430 – 2. Coil B.

431 – 1. The frequency of the applied AC voltage and the number of pole pairs.

431 – 2. $\text{RPM} = \frac{60 \times \text{applied AC frequency}}{\text{number of pole pairs}}$

432 – 1. From the fact that currents are induced in the rotor by the rotating magnetic field of the stator.
432 – 2. Heavy copper bars connected at each end by a metal ring.
432 – 3. A current is induced in the rotor circuit by the rotating magnetic field in the stator. The rotating magnetic field of the stator induces voltage into the rotor; the generated voltage causes current rasulting in a rotor electromagnet which follows the rotating stator electromagnet.
432 – 4. Slip is the percentage difference between the rotational speed of the stator field and the rotor.

433 – 1. Split phase refers to the split of the single-phase input voltage within the motor.
433 – 2. By inserting a capacitor or resistor in series with one field coil winding.
433 – 3. A capacitor-start, capacitor-run induction motor.
433 – 4. The shaded-pole induction motor.

434 – 1. A force is exerted between stationary and movable magnetic fields. The amount and direction of this force determines motor speed and direction of rotation.
434 – 2. The conductor reverses its direction.

435 – 1. Neutral plane means the position of zero torque which occurs when the coil is perpendicular to the fixed magnetic field.
435 – 2. By increasing the strength of the field magnets and by placing additional coils within the magnet's field.
435 – 3. Counter-electromotive force (CEMF), induced in the armature as it moves with the magnetic field.
435 – 4. By increasing the rate (motor speed) at which the armature cuts the magnetic field and by increasing the strength of the magnetic field.

436 – 1. In series.
436 – 2. High starting torque and poor speed regulation.
436 – 3. It will continue to accelerate to a very high speed which may cause extensive damage.
436 – 4. By reversing current flow in a field winding or reversing current flow in the armature.
436 – 5. A split-field series motor is a series motor with two field windings. Current through one winding causes motor rotation in one direction and current through the other winding causes the motor to reverse direction.

437 – 1. They are connected in parallel.
437 – 2. Low starting torque and good speed regulation.
437 – 3.
  a. Shunt.
  b. Series.
  c. Series.
  d. Shunt.
  e. Series.

438 – 1. Constant speed and high torque.
438 – 2. Speed regulation.
438 – 3. No effect.
438 – 4. Series and shunt field windings are wound in the same direction in a cumulative-compound motor, while the differential-compound motor has its series and shunt windings wound in opposite directions to each other.

CHAPTER 4

439 – 1. Inductance is the property of a circuit that opposes any change in current flow. The symbol is the letter "L."
439 – 2. Mutual induction is the action of inducing a voltage in one circuit by varying the current in some other circuit. The symbol is the letter "M."
439 – 3. A henry is the inductance in a circuit that induces an EMF of 1 volt when the current is changing at a rate of 1 ampere per second. The symbol is the letter "H."
439 – 4. Flux linkage is the interlocking of magnetic lines of force; it is the magnetic lines around one coil or wire that link another coil, or wire.

440 – 1. The number of turns in the coil, the diameter of the coil, the coil length, and material in the core.
440 – 2. Soft iron core.

441 – 1. $L_t = 33$ henries.
441 – 2. $L_t = 5.4$ henries.
441 – 3. $L_t = 3.2$ henries.

442 – 1. The rate of change of current flow.
442 – 2. The direction of current flow through the coil and whether the current flow is increasing or decreasing.
442 – 3. Voltage leads current by 90°.

443 – 1. Energy dissipated without doing work.
443 – 2. Increase the size of the conductor, thus reducing heat and resistance.
443 – 3. Use a core material with a high permeability.
443 – 4. The insulation between layers does not oppose the magnetic flux, but reduces eddy currents by limiting the paths for current flow.

444 – 1. The opposition to current flow offered by the inductance of a circuit.
444 – 2. Ohms.
444 – 3.
  a. 15,072 ohms.
  b. 113.04 ohms.
  c. 879.2 ohms.
444 – 4. It doubles.
445 – 1. The primary.
445 – 2. The secondary.
445 – 3. A core of low-reluctance magnetic material.
445 – 4. An iron-core transformer.
446 – 1. The ratio of the number of turns in the primary to the number of turns in the secondary.
446 – 2. It has a 5 to 1 ratio or a step-down turns ratio.
446 – 3. $\frac{N_p}{N_s} = \frac{E_p}{E_s}$
446 – 4. The extent to which magnetic lines of the primary cut across the secondary.
446 – 5. That 90 percent of the lines of flux of the primary winding are cutting the secondary winding.
446 – 6. The total primary power equals secondary power.
446 – 7. An increase in voltage in the primary means a decrease in current and vice versa.

447 – 1. The autotransformer, the power transformer, the audio transformer, and the RF transformer.
447 – 2. It has only one winding.

448 – 1. An open in the secondary winding.
448 – 2. The secondary has some shorted windings.

449 – 1. You may use a resistance reading. (In a step-down transformer the resistance of the secondary is less than that of the primary, and in a step-up, the secondary has the higher resistance.) You may also apply a voltage being careful to not exceed the rating of the transformer or the meter. If you apply 10 volts to the primary and read 20 volts in the secondary, it is a step-up transformer, but if you read 5 in secondary, then it is a step-down transformer.

450 – 1. Magnetomotive force (MMF), flux, and reluctance.
450 – 2. The B-H ratio is the basis for selecting core materials for saturable reactors. It is the measure of the permeability of a material and is expressed as:
$$\mu = \frac{\text{B (flux density)}}{\text{H (magnetizing force)}}$$
450 – 3. The instep section represents the time during which the magnetizing force is rearranging the molecules in the iron core.
450 – 4. A hysteresis loop is caused when the flux density lags behind the magnetizing force.
450 – 5. The ideal hysteresis loop is rectangular in shape and very narrow in width.

451 – 1. The saturable reactor is a toroidal-shaped coil that functions as a synchronous switch because the impedance of the reactor changes abruptly from a high impedance to a low impedance during each half-cycle of applied line voltage.
451 – 2. Add a control winding. Connect this winding to a DC source and apply a magnetizing force to the control coil. A variable resistor controls this steady magnetizing current.

451 – 3. By designing a very high impedance in the control circuit, placing an iron-core choke coil in the control circuit, and using two separate core elements, called a twin-coil arrangement.

452 – 1. When it is fully charged.
452 – 2. To the applied voltage and the capacity of the capacitor.
452 – 3. A farad is the capacity of a capacitor to charge to 1 coulomb (6.28×10^{18} electrons) with a difference of 1 volt potential across the plates.
452 – 4. The plate surface area, the dielectric thickness or plate spacing, and the dielectric material.
452 – 5. Working voltage is the maximum DC value that can be applied to a capacitor continuously. It depends largely on the dielectric material of the capacitor.

453 – 1. Fixed and variable.
453 – 2. 600.
453 – 3. High-power circuits with medium high voltage.
453 – 4. In high-frequency circuits subjected to voltages up to 7500 volts.
453 – 5. Electrolytic.
453 – 6. Its high power loss.
453 – 7. Ceramic capacitors.
453 – 8. The power and voltage in the circuit.
453 – 9. Trimmers, which are used in parallel with larger variable capacitors, and padders, which are used in series with larger capacitors.

454 – 1. When it contains a potential equal and opposite to the charging source.
454 – 2. When voltage is at its peak value.
454 – 3. It leads capacitor voltage by 90°.

455 – 1. The opposition of a capacitor to the flow of current.
455 – 2. Frequency and size of the capacitor.
455 – 3. The ohm.
455 – 4. a. 318 ohms.
  b. 39,750 ohms.
  c. 159 ohms.
455 – 5. Add capacitors in series-like resistors in parallel, and add capacitors in parallel-like resistors in series.
455 – 6. a. $C_t = .15\mu f$.
  b. $C_t = .0167\mu f$.
  c. $C_t = .25\mu f$.
455 – 7. $E_c = I_c X_c,\ I_c = E_c,\ X_c = \frac{E_c}{I_c}$

456 – 1. Nothing is wrong, the capacitor is good.
456 – 2. An open capacitor.

CHAPTER 5

457 – 1. In phase.
457 – 2. 90° out of phase.
457 – 3. A vector is a line that represents magnitude and direction.
457 – 4. An in-phase condition.

458 – 1. The voltage across the resistor is in phase with the current, and the voltage across the capacitor lags the current by 90°.
458 – 2. The voltage across the resistor is in phase with the current and the voltage across the inductor leads the current by 90°.
458 – 3. The voltage across the capacitor is 180° out of phase with the voltage across the inductor.
458 – 4. As the frequency of the voltage increases the reactance of the capacitor decreases while the reactance of the inductor increases.

459 – 1. The power output is at maximum value during both the positive and negative values of voltage and current.
459 – 2. Zero.
459 – 3. Zero.

460 – 1. Total circuit voltage.
460 – 2. The phase relationship is 90° in the capacitive branch, and in phase in the resistive branch.
460 – 3. Total impedance is less than the value of the smallest resistance or reactance.
460 – 4. Total current is the vector sum of I_c and I_R.
460 – 5. True power is the power that is dissipated by the resistance.
460 – 6. When reactive and resistive components are connected in a circuit, the circuit appears to use much more power than it actually dissipates. This is called the apparent power.

461 – 1. Resistor, capacitor, and inductor.
461 – 2. I is at maximum and Z is at minimum.
461 – 3. X_c decreases and X_L increases.
461 – 4. Above resonance.
461 – 5. The resonant frequency decreases.
461 – 6. X_c decreases and X_L increases.
461 – 7. Current lags voltage.
461 – 8. By subtracting the lower frequency from the upper frequency of the half-power points.
461 – 9. The low-pass filter passes low frequencies and blocks high frequencies. The high-pass filter passes high frequencies, and blocks low frequencies.

462 – 1. The capacitor and inductor.
462 – 2. X_c must equal X_L.
462 – 3. Less reactance than at a high frequency.
462 – 4. A capacitor and an inductor.
462 – 5. Line current is maximum.

463 – 1. It is an exact reproduction of the input signal. Thus, the input and output signals are in phase.
463 – 2. A phase shift occurs across an RC-coupling circuit. The phase shift is some angle between 0° and 90°, depending on the frequency.
463 – 3. As frequency increases, X_c decreases and X_L increases. This causes the output to increase. At some frequency, C and L become resonant. The output is then more than the input.
463 – 4. Transformer-type coupling.

CHAPTER 6

464 – 1. (1) d, (2) b, (3) a, and (4) c.
464 – 2. To prevent the gas from bouncing the electrons back to the emitter and to prevent the emitter form oxidizing and destroying itself.
464 – 3. The temperature and the size of the emitter.
464 – 4. The directly heated cathode.
464 – 5. An indirectly heated cathode.
464 – 6. The line voltage.
464 – 7. A resistor is connected in parallel across the tube.

465 – 1. The cathode and the plate.
465 – 2. Plate current.
465 – 3. Pulsating direct current.
465 – 4. DC plate resistance is doubled.

466 – 1. A grid, a cathode, and a plate.
466 – 2. Decreased.
466 – 3. Amplification.
466 – 4. Static curves.
466 – 5. Dynamic curves.
466 – 6. Bias.
466 – 7. Fixed bias, cathode self-bias, and grid-leak bias.
466 – 8. Cathode self-bias.
466 – 9. Plate and cathode, grid and cathode, and grid and plate.
466 – 10. Grid-to-plate.

467 – 1. It reduces capacitance and increases amplification.
467 – 2. The control-grid and screen-grid potentials.
467 – 3. Negative resistance; dynatron.
467 – 4. Secondary emission.
467 – 5. High.

468 – 1. b, d, e.

469 – 1. (1) e; (2) a,f; (3) g, b; (4) h; (5) d; and (6) c.
469 – 2. To transfer an input signal from a high-impedance network to a low-impedance network with maximum power.

CHAPTER 7

470 – 1. Centrifugal, which tends to cause an electron to fly outward as it travels, and centripetal, which tends to pull the electron in towards the atom's nucleus.

521

470 – 2. Kinetic and potential.
470 – 3. A level in an atom where electrons may establish orbits.
470 – 4. By forbidden energy leads.
470 – 5. An electron cannot exist in the space between permissible energy levels.
470 – 6. An electron in the outermost shell or an atom which enters into chemical or electrical combinations with other atoms.

471 – 1. The solid permissible energy level that is formed by the interaction of valence shell levels when a number of atoms are brought together.
471 – 2. A permissible energy level that is formed by unoccupied shells when a number of atoms are brought together.
471 – 3. An electron that has reached the conduction band and is free from the nucleus.
471 – 4. A conductor.
471 – 5. A substance that contains few free electrons.
471 – 6. Semiconductor.

472 – 1. A measure of its ability to combine with other elements.
472 – 2. The force that holds two different atoms together when they share valence electrons.
472 – 3. When the atoms or molecules are arranged in definite repeating patterns and the external surface is a symmetrical arrangement.
472 – 4. The generation of an electron-hole pair.
472 – 5. Positive; negative.

473 – 1. A crystal with impurities added.
473 – 2. Doping.
473 – 3. A negative-carrier or N-type semiconductor.
473 – 4. An acceptor impurity.
473 – 5. A positive-carrier or P-type semiconductor.

474 – 1. An atom that has lost an electron. It occurs in N-type material.
474 – 2. An atom that has an excess of electrons. It occurs in P-type mateial.
474 – 3. Electrons.
474 – 4. Holes.

475 – 1. Negative; positive.
475 – 2. As temperature increases, resistance decreases.
475 – 3. Positive; negative.

476 – 1. Donor impurities are added to one part of the crystal in a P–N junction diode, and acceptor impurities are added to the other section. This gives a P section and an N section. The area between the P and N sections is called a junction. Metallic contacts are then bonded to the two ends of the crystal.
476 – 2. The difference of potential across the depletion region.
476 – 3. Electron-hole pairs are formed at random when the crystal is subjected to heat, light, or electromagnetic radiation.
476 – 4. The movement of minority carriers where free electrons produced on the P side of the junction pass across the junction and neutralize some positive ions on the N side of the junction.

477 – 1. A battery is connected across the P–N junction in such a way that the voltage opposes the barrier potential across the width of the junction barrier and thereby aids current flow through the junction.
477 – 2. The positive terminal of the battery is connected to the P-type material and the negative terminal is connected to the N-type material.
477 – 3. Majority current carriers.
477 – 4. Yes, the minority carriers are responsible for a small current flow.
477 – 5. Minority current increases.

478 – 1. The bar represents the cathode and the arrow represents the anode.
478 – 2. Against the arrow.
478 – 3. Maximum average forward current, peak forward current, maximum surge current, and peak reverse voltage (PRV).
478 – 4. The maximum amount of average current that can be permitted to flow in the forward direction.
478 – 5. The maximum peak current that can be permitted to flow in the forward direction in recurring pulses.
478 – 6. The maximum reverse bias voltage that can be applied to a diode without causing structure breakdown.
478 – 7. The maximum current permitted to flow in the forward direction in the form of nonrecurring pulses.
478 – 8. Nonlinear.
478 – 9. Avalanche breakdown.
478 – 10. When the applied voltage is sufficiently large to break down the covalent band structure to break down.

479 – 1. Emitter-gives off current carriers (electrons or holes), the base controls their flow, and the collector collects them.
479 – 2. N–P–N and P–N–P.
479 – 3. The N–P–N transistor is formed by introducing a thin region of P-type material between two regions of N-type material in a single crystal of germanium or silicon. The P–N–P transistor is formed by introducing a thin region of N-type material between two regions of P-type material.

480 – 1. The emitter-base junction is forward biased and the collector-base junction is reverse biased.
480 – 2. Some of the electrons recombine with holes, move out through the base lead in the form of base current (I_B), and return to the emitter supply battery, V_{EE}.
480 – 3. The current's path is from the negative terminal of the emitter supply battery to the emitter. It flows through the emitter to the base. From the base a small portion returns to the positive terminal of the emitter battery. The rest flows from the base through the collector to the positive terminal of the collector battery as collector current (I_c).
480 – 4. Opposite.

481 – 1. The flow of charge carriers under the influence of an electric field.
481 – 2. A charge flow caused by an unequal density of charge carriers in a material.
481 – 3. If the base region is too wide, the electrons injected into the base by the emitter will recombine and leave the transistor as base current (I_B).
481 – 4. To increase the chance of collecting carriers that diffuse to the side as well as directly across the base region and to give it a larger heat dissipation factor.

482 – 1. It appears as low resitance.
482 – 2. Minority carriers.
482 – 3. Because the base is very thin, and is lightly doped, reducing the chance for recombination.
482 – 4. In the emitter lead.
482 – 5. The emitter-base voltage.
482 – 6. The collector current would decrease.
482 – 7. The emitter-base voltage control is nonlinear.
482 – 8. Bias is the average DC voltage or current used to control the operating point.

483 – 1. Always against the arrow.
483 – 2. Always toward the base.
483 – 3. Always away from the base.

484 – 1. Common-emitter, common base, and common-collector.
484 – 2. It is 180° out of phase with the output.
484 – 3. It is the highest of the three.
484 – 4. It has a low response to high frequencies.
484 – 5. Alpha.
484 – 6. The input impedance is low.
484 – 7. There is no phase reversal of a grounded-base transistor.
484 – 8. An emitter follower.
484 – 9. There is no phase reversal in a common collector between input and output.
484 – 10. High input impedance and low output impedance.

485 – 1. A characteristic curve is a graph, plotted to show the relationships of changing values.
485 – 2. The beta (theoretical current gain) and how resistance changes with a given charge in forward bias.

486 – 1. An AC source and a rectifier.
486 – 2. The half-wave rectifier.
486 – 3. Whether the DC output is positive or negative.
486 – 4. Filters.
486 – 5. Two.
486 – 6. The peak inverse voltage rating of the semiconducotr diode.

486 - 7. Twice the input.

487 - 1. The collector-coupled multivibrator.
487 - 2. Symmetrical.
487 - 3. The base of Q1 starts going negative, and the base of Q2 starts going positive.

488 - 1. A one-shot multivibrator will never become free running because it must be triggered each time it fires.
488 - 2. The output frequency of a one-shot multivibrator is one-half of the input frequency.

CHAPTER 8

489 - 1. To solve equations and produce a voltage representing an angle.
489 - 2. 50 volts.
489 - 3. 25 volts.
489 - 4. Zero volts (because the sine winding is set at 90°.
489 - 5. A magnetic resolver produces a true cosine wave (and possibly a true sine wave), whereas the output of a linear pot resolver is a straight-line approximation of a sine or cosine curve.

490 - 1. To actuate the switch as selected positions of shaft rotation.
490 - 2. If a cam slips on its shaft, the circuits actuated by the cam and microswitch will not be energized at the proper time.

491 - 1. Synchros.
491 - 2. Rapid and accurate transmission of information between equipment and stations.

491a- 1. Torque systems and control systems.
491a- 2. A torque synchro is used for light loads, and a control synchro is used in systems designed to move heavy loads.
491a- 3. Torque receiver.

491b- 1. The code 26V-11TX4d means that it is the third modification of a 26-volt 400-hertz torque synchro transmitter that has a body diameter between 1.01 and 1.10 inches.

491c- 1. The small arrow on the rotor symbol.
491c- 2. When it is important to see the positional relationship between the rotor and stator.

491d- 1. Rotor and stator.
491d- 2. The drum (or wound) rotor.
491d- 3. Magnetic coupling (induction) from the rotor.
491d- 4. At the terminal board.

491e- 1. A measure of how much load a machine can turn.
491e- 2. Ounce-inches.
491e- 3. The number and type of synchro receivers, the mechanical loads on these receivers, and the operating temperatures of both the transmitter and receivers.
491e- 4. It indicates how much force is required to turn the rotor 1°.
491e- 5. Aircraft equipment.
491e- 6. When it is overloaded.

491f- 1. In a conventional transformer, the windings are fixed. Synchros have one primary winding that can be turned through 360° and three secondary windings spaced 120° apart.
491f- 2. The transmitter is in its *zero* position when the rotor is aligned with the S2 stator winding.

491g- 1. When the rotor coil is aligned with the stator coil.
491g- 2. The amplitude of the primary voltage, the turns ratio, and the angular displacement between the rotor and stator windings.

491h- 1. A synchro receiver uses some form of damping to retard excessive oscillations or spinning.
491h- 2. Mechanical damping.

491i- 1. Transmitter and receiver.
491i- 2. Rotor leads.
491i- 3. Equal and opposing each other.
491i- 4. Signal.

491j- 1. S1 and S2.
491j- 2. Reversed rotor leads on either the transmitter or receiver.

491k- 1. Control synchro.
491k- 2. CX, CT, and CDX.
491k- 3. The CX has higher impedance windings than a TX.
491k- 4. The rotor is specially wound, it is never connected to an AC supply, and its output is always applied to a high-impedance load.

491l- 1. The rotor and the S2 winding are perpendicular to each other.
491l- 2. The voltage is maximum and in phase with the AC excitation voltage.
491l- 3. Error signal.
491l- 4. When the CX and CT rotors are in correspondence.

491m- 1. Electrical zero.
491m- 2. Voltmeter method.
491m- 3. Ensures that the synchro is on 0°, not 180°.
491n- 1. Circuits B, D, E, and F.
491n- 2. Causes the signal to be shifted 120°.
491n- 3. Circuit E only.
491n- 4. If the indication displayed by the receiver is reversed at zero, only S1 and S3 are crossed. If the indication is reversed at all readings, the rotor leads are crossed.

CHAPTER 9

492 - 1. The value of a digit depends on its position within a number.
492 - 2. Zero.
492 - 3. The number of symbols used in a numbering system.
492 - 4. 10 is the base, 1,000 is the power, and 3 is the exponent.
492 - 5. The product of the base used as a factor a number of times equal to the exponent.
492 - 6. The 6 is the MSD, and the 8 is the LSD.

493 - 1. Its two characters, one and zero, can be handled by the digital computer's bistable switches, relays, electronic tubes, and solid-state devices.
493 - 2. The power doubles.
493 - 3. The power is halved.

494 - 1. $76_{(10)} = 1001100$.
494 - 2. $212_{(10)} = 11010100$.
494 - 3. $63_{(10)} = 111111$.
494 - 4. $21_{(10)} = 10101$.
494 - 5. $1409_{(10)} = 10110000001$.
494 - 6. $855_{(10)} = 1101010111$.

495 - 1. $.436_{(10)} = .011011$.
495 - 2. $.75_{(10)} = .11$.
495 - 3. $23.125_{(10)} = 10111.001$.
495 - 4. $175.789_{(10)} = 10101111.110010$.
495 - 5. $69.963_{(10)} = 1000101.111101$.
495 - 6. $928.441_{(10)} = 1110100000.011100$.

496 - 1. $1101_{(2)} = 13$.
496 - 2. $1000_{(2)} = 8$.

496 - 3. $10111_{(2)} = 23.$
496 - 4. $101100_{(2)} = 44.$
496 - 5. $111111_{(2)} = 63.$

497 - 1. $.110001_{(2)} = .765625.$
497 - 2. $.00011_{(2)} = .09375.$
497 - 3. $11.11010_{(2)} = 3.8125.$
497 - 4. $1011.01000_{(2)} = 11.25.$
497 - 5. $1111.10111_{(2)} = 15.71875.$

498 - 1. 1001001.
498 - 2. 1000.0000.
498 - 3. 11101.11.
498 - 4. 11000.011.
498 - 5. 1100.10.
498 - 6. 101100.10.

499 - 1. 100.
499 - 2. 1101.
499 - 3. 1.11.
499 - 4. 10.
499 - 5. .01.
499 - 6. .1.

500 - 1. 1000001.
500 - 2. 11.011.
500 - 3. 10101.0101.
500 - 4. 1001101.
500 - 5. 111010000.
500 - 6. 1110.0001.

501 - 1. 11100.
501 - 2. 1.0110.
501 - 3. 10.0110.
501 - 4. 10.1111.
501 - 5. 10.0011.
501 - 6. 100.

502 - 1. $161_{(8)}.$
502 - 2. $736_{(8)}.$
502 - 3. $64.3274_{(8)}.$
502 - 4. $2730.1103_{(8)}.$
502 - 5. $62_{(10)}.$
502 - 6. $106_{(10)}.$
502 - 7. $489.218750_{(10)}.$
502 - 8. $148.484375_{(10)}.$

503 - 1. $16.4_{(8)}.$
503 - 2. $55.3_{(8)}.$
503 - 3. $2.34_{(8)}.$
503 - 4. $55.5_{(8)}.$
503 - 5. $110100.01101_{(2)}.$
503 - 6. $101001110100_{(2)}.$
503 - 7. $100011111.110101_{(2)}.$
503 - 8. $.111111011_{(2)}.$

504 - 1. 777.
504 - 2. 565.06.
504 - 3. 1.3573.
504 - 4. 723.61.
504 - 5. 4751.
504 - 6. 6607.
504 - 7. 3121.34.
504 - 8. 110.71.
504 - 9. 1.3506.
504 - 10. 1.13452.

505 - 1. 011100110010.
505 - 2. 011001000011.
505 - 3. 1001010001010001.
505 - 4. 597.
505 - 5. 292.
505 - 6. 81.

506 - 1. 01011010.

STOP-

1. **MATCH ANSWER SHEET TO THIS EXERCISE NUMBER.**
2. ***USE NUMBER 2 PENCIL ONLY.***

EXTENSION COURSE INSTITUTE
VOLUME REVIEW EXERCISE

32551 03 24

ELECTRONIC PRINCIPLES

Carefully read the following:

DO's:

1. Check the "course," "volume," and "form" numbers from the answer sheet address tab against the "VRE answer sheet identification number" in the righthand column of the shipping list. If numbers do not match, return the answer sheet and the shipping list to ECI immediately with a note of explanation.
2. Note that item numbers on answer sheet are sequential in each column.
3. Use a medium sharp #2 black lead pencil for marking answer sheet.
4. Write the correct answer in the margin at the left of the item. (When you review for the course examination, you can cover *your* answers with a strip of paper and then check your review answers against your original choices.) After you are sure of your answers, transfer them to the answer sheet. If you *have* to change an answer on the answer sheet, be sure that the erasure is complete. Use a clean eraser. But try to avoid any erasure on the answer sheet if at all possible.
5. Take action to return entire answer sheet to ECI.
6. Keep Volume Review Exercise booklet for review and reference.
7. If *mandatorily* enrolled student, process questions or comments through your unit trainer or OJT supervisor. If *voluntarily* enrolled student, send questions or comments to ECI on ECI Form 17.

DON'Ts:

1. Don't use answer sheets other than one furnished specifically for each review exercise.
2. Don't mark on the answer sheet except to fill in marking blocks. Double marks or excessive markings which overflow marking blocks will register as errors.
3. Don't fold, spindle, staple, tape, or mutilate the answer sheet.
4. Don't use ink or any marking other than a #2 black lead pencil.

NOTE: **NUMBERED LEARNING OBJECTIVE REFERENCES ARE USED ON THE VOLUME REVIEW EXERCISE.** In parenthesis after each item number on the VRE is the *Learning Objective Number* where the answer to that item can be located. When answering the items on the VRE, refer to the *Learning Objectives* indicated by these *Numbers*. The VRE results will be sent to you on a postcard which will list the *actual* VRE *items you missed*. Go to the VRE booklet and locate the *Learning Objective Numbers* for the items missed. Go to the text and carefully review the areas covered by these references. Review the entire VRE again before you take the closed-book Course Examination.

MULTIPLE CHOICE

Note to Student: Consider all choices carefully and select the *best* answer to each question.

1. (400) What causes current to flow?

   a. Ampere.
   b. Resistance.
   c. Electromotive force.
   d. 6.28 × 1018 coulombs passing a given point in one second.

2. (401) The resistance of a conductor is

   a. inversely proportional to its cross-sectional area.
   b. directly proportional to its cross-sectional area.
   c. so small it can be considered negligible.
   d. inversely proportional to its length.

3. (401) When we say that a resistor has a negative temperature coefficient we mean that as the temperature

   a. increases the resistance increases.
   b. increases the resistance decreases.
   c. decreases the resistance decreases.
   d. changes the resistance remains relatively constant.

4. (402) What is the color code of a 560 ohm resistor?

   a. Green - blue - black - gold.
   b. Green - brown - blue - silver.
   c. Green - blue - brown - silver.
   d. Green - blue - gray - no color.

5. (403) What are the requirements for a practical basic electrical circuit?

   a. An EMF source, a conductor, and a load.
   b. A complete circuit and an EMF source.
   c. An EMF source and a conductor.
   d. An EMF source and a load.

6. (404) The number 79,681 is equivalent to

   a. 7.9681×10^5.
   b. 7.9681×10^4.
   c. 7.9681×10^3.
   d. 79.681×10^2.

7. (405) 100×10^6 ohms is equal to

   a. 10,000,000 ohms.
   b. 100×10^3 milliohms.
   c. 100×10^6 megohms.
   d. 100 megohms.

8. (406) An equation expressed in numerical terms

   a. must be kept in balance through each step of the solution.
   b. does not balance until the final solution is reached.
   c. always produces a positive figure.
   d. is an axiom.

9. (407) To solve for I in the equation E = IR, you must

a. divide by E.
b. divide by R.
c. multiply by R.
d. cross multiply E by I.

10. (408) What term is used to describe the ease with which magnetic lines of force will pass through a material?

a. Permeability.
b. Retentivity.
c. Reluctance.
d. Force.

11. (409) The product of the number of turns times the current flowing in a coil is called

a. ampere capacity.
b. turns ratio.
c. ampere-turns.
d. saturation.

12. (410) What is another name used for an electrically-operated switch?

a. Core.
b. Relay.
c. Contacts.
d. Armature.

13. (410) An electromagnetic relay used as a vibrator can change

a. direct current to alternating current.
b. alternating current to direct current.
c. direct current to pulsating direct current.
d. pulsating direct current to direct current.

14. (411) In a DC series circuit, the total current is equal to

a. all the currents at various points added together.
b. the total resistance divided by the total voltage.
c. the current at any point in the circuit.
d. none of the above.

15. (411) If the voltage in a series DC circuit is doubled and the resistance is held constant, the current must

a. double.
b. decrease.
c. increase one-half.
d. reduce one-half.

16. (412) The time rate of developing energy is defined as

a. force.
b. power.
c. a watt.
d. joule.

17. (413) The ground symbol used in a voltage divider denotes a

a. voltage source.
b. current source.
c. reference point.
d. conducting chassis.

18. (414) When the slider is moved on a potentiometer connected in a circuit, there will be a noticeable change in the output

a. voltage.
b. current.
c. impedance.
d. resistance.

19. (415) Total current in a parallel circuit is equal to the

a. current in each loop.
b. sum of the currents in each loop.
c. square of the current in each loop.
d. total resistance divided by the total voltage.

20. (415) The formula for calculating power is

a. $P = RI$.
b. $P = ER$.
c. $P = IE$.
d. $P = I^2E$.

21. (416) If you are troubleshooting a parallel resistance circuit with an ammeter and one leg of the parallel circuit is open, what will the ammeter indicate if it is connected in series with the entire circuit?

a. Normal amperage reading.
b. Zero amperage reading.
c. High amperage reading.
d. Low amperage reading.

22. (417) In a circuit with three parallel legs, one leg is a 10 and 15 ohm resistor in series and the other two legs are 25 ohms each. What is the total resistance of the circuit?

a. 37.5 ohms.
b. 25 ohms.
c. 12.5 ohms.
d. 8.3 ohms.

23. (418) What is the ohmmeter reading across a shorted component in a series-parallel circuit?

a. Infinity.
b. Continuity.
c. Higher than normal.
d. Resistance of the other resistors.

24. (419) When a load is connected across a voltage divider, total circuit resistance

a. decreases.
b. increases.
c. remains the same.
d. may increase or decrease.

25. (421) What term represents the difference between the maximum positive and the maximum negative values of an AC sine wave?

a. Peak-to-peak value.
b. Effective value.
c. Average value.
d. RMS value.

26. (421) Of the following terms, which one can be used to identify the effective value of AC?

a. Peak-to-peak.
b. Average.
c. Peak.
d. RMS.

27. (422) The term used to indicate the number of cycles of AC that occur in one second is called

a. RMS value.
b. amplitude.
c. frequency.
d. reversals.

28. (423) What are the three requirements for induction?

a. A coil, a core, and relative motion.
b. An electromagnetic, a conductor, and sliprings.
c. A magnetic field, sliprings, and relative motion.
d. A conductor, a magnetic field, and relative motion.

29. (424) If a conductor is moved perpendicular to the lines of force back and forth through a magnetic field, current flow in the conductor will

a. alternate.
b. be a pure DC.
c. be stationary.
d. see a very high resistance.

30. (425) What three factors can vary the magnitude of induced current in a generator?

a. Strength of magnetic field, number of conductors, and speed of rotation of conductor.
b. Strength of magnetic field, number of conductors, and the temperature of the conductors.
c. Speed of rotation of the conductors, number of conductors, and temperature of the conductors.
d. Strength of magnetic field, speed of rotation of the conductors, and the temperature of the conductors.

31. (426) The external circuit and load make it possible for an AC generator to

a. produce a higher frequency.
b. produce a higher output.
c. accomplish useful work.
d. reverse its rotation.

32. (427) A basic DC generator differs from an AC generator only in the use of

a. brushes.
b. an armature.
c. pole pieces.
d. a commutator.

33. (428) The amount of DC variation in a generator output may be decreased by

a. speeding up the generator.
b. creating a stronger magnetic field.
c. increasing the number of loops in the armature.
d. increasing the number of armature conductors per coil.

34. (430) If a three phase AC motor has the field coils spaced 120° apart, what can be done to make the motor operate smoother?

a. Split the field coils so they are 60° apart.
b. Divide the field coils so they will be 180° apart.
c. Increase the amount of segments in the armature.
d. Apply a higher current value through the sliprings.

35. (431) What best determines the speed of the rotating field of a synchronous motor?

a. Number of segments in the armature.
b. Strength of the field.
c. Number of pole pairs.
d. Input frequency and number of poles.

36. (433) What type of induction motor normally has a very small torque and horsepower rating?

a. Capacitor-start motor.
b. Shaded-pole motor.
c. Split-field motor.
d. Split-phase motor.

37. (434) All electric motors operate on the principle of

a. phase relationship of the armature and field.
b. phase relationship of inductors and capacitors.
c. charging and discharging of the electromagnet used as a rotor.
d. force exerted between stationary and movable magnetic fields.

38. (435) When the coil is perpendicular to the fixed magnetic field,

a. saturation occurs.
b. the torque is zero.
c. the torque is maximum.
d. coil movement immediately stops.

39. (436) What are the two main characteristics of series motors?

a. High starting torque and good speed regulation.
b. *High starting torque and poor speed regulation.*
c. Low starting torque and poor speed regulation.
d. Low starting torque and good speed regulation.

40. (437) Select the operating characteristics, of a shunt motor?

a. High starting torque and good speed regulation.
b. High starting torque and poor speed regulation.
c. Low starting torque and good speed regulation.
d. Low starting torque and poor speed regulation.

41. (438) What is the main difference between the cumulative-compound and differential-compound motors?

a. The way the windings are excited.
b. The placement of the shunt field.
c. The direction of the field windings.
d. The direction of current in the armature.

42. (440) Which of the following factors would decrease the inductance of a coil?

a. Adding turns.
b. Adding a second layer.
c. Removing soft-iron core.
d. Increasing diameter to length ratio.

43. (441) The rules for computing total inductance for several inductors in series or parallel are similar to those used for computing total

a. power.
b. voltage.
c. current.
d. resistance.

44. (442) In an inductor, the amplitude of the induced voltage is determined by the

a. rate of change of current flow.
b. direction of current flow.
c. polarity of current flow.
d. applied voltage.

45. (443) Which of the following power losses may be reduced by using a core of higher permeability?

a. Copper.
b. Hysteresis.
c. Lamination.
d. Eddy current.

46. (444) If a coil has an inductance of 7 henries and is placed in a circuit having a 115-volt, 60-hertz applied, what is the inductive reactance?

a. 1318.8 ohms.
b. 2637.6 ohms.
c. 5055.4 ohms.
d. 43,332 ohms.

47. (445) Transformers used in low-frequency circuits require

a. an air core.
b. a turns ratio of at least 10:1.
c. a core of low-reluctance magnetic material.
d. a core of high-reluctance magnetic material.

48. (446) A transformer with 100-percent efficiency has 100 volts applied to the primary and the output on the secondary is 10 volts. If the load consumes 30 watts of power, what is the primary current?

a. 30 amps.
b. 3 amps.
c. .3 amps.
d. .03 amps.

49. (447) Which type of transformer uses a single winding that is tapped for the primary and secondary?

a. Audio transformer.
b. Power transformer.
c. Autotransformer.
d. RF transformer.

50. (448) An open transformer primary would be indicated on an ohmmeter by a reading of

a. zero between the two primary leads.
b. infinity between the two primary leads.
c. zero between the primary and secondary.
d. high resistance between the two primary leads.

51. (449) If a transformer has a turns ratio of 7 to 1 and is 100 per cent efficient, what is the secondary voltage if 210 volts is applied to the primary?

a. 7 volts.
b. 30 volts.
c. 300 volts.
d. 1470 volts.

52. (450) In an electromagnet, as the magnetizing forces increase, flux

a. increases.
b. decreases.
c. remains the same.
d. may increase or decrease.

53. (451) If true, why is a saturable reactor considered an amplifier?

a. A small amount of power is controlled by a large amount of power.
b. A saturable reactor amplifies magnetism.
c. Magnetic flux increases after saturation occurs.
d. None of the above are true.

54. (452) The dielectric thickness or spacing between the plates of a capacitor is

a. inversely proportional to the plate surface area.
b. directly proportional to the plate surface area.
c. directly proportional to the capacitance of the capacitor.
d. inversely proportional to the capacitance of the capacitor.

55. (453) Electrolytic capacitors

a. show polarity and can handle relatively high power at low frequencies.
b. handle high power, high frequencies, and only DC voltages.
c. will operate only in low-frequency RF circuits.
d. show polarity and must be mounted upright.

56. (454) Across a capacitor, what is the relationship to the rate of change in capacitor current to the rate of change in capacitor voltage?

a. Directly proportional.
b. Inversely proportional.
c. Current changes faster than voltage.
d. Voltage changes faster than current.

57. (455) As the frequency to a capacitor increases,

a. capacitance decreases.
b. capacitance increases.
c. capacitive reactance increases.
d. capacitive reactance decreases.

58. (456) When checking a capacitor, what is indicated if the needle of an ohmmeter deflects momentarily and then drops back to infinity?

a. A good capacitor.
b. A leaky capacitor.
c. A shorted capacitor.
d. An open capacitor.

59. (457) A vector representing voltage in a purely resistive circuit is drawn

a. in the same plane and direction as the current vector.
b. in the same plane and opposing the current vector.
c. at an angle -90° to the current vector.
d. at an angle +90° to the current vector.

60. (458) In an RC series circuit, what effect if any, does increasing Xc have on R?

a. R increases.
b. R decreases.
c. Has no effect on R.
d. Cannot be determined.

61. (458) In a series RC circuit, if the Z phase angle is -45 degrees

a. X_c is equal to R.
b. X_c is greater than R.
c. X_c is smaller than R.
d. the circuit will appear capacitive.

62. (459) What is the average power output in a purely AC inductive circuit?

a. Cannot be determined.
b. Maximum.
c. Minimum.
d. Zero.

63. (460) In a parallel reactive circuit, total current is equal to the

a. sum of the individual branches currents.
b. vector sum of the individual branch currents.
c. current in any one of the individual branches currents.
d. square of the current in any one of the individual branch currents.

64. (461) In a series RCL circuit where $E_c = 10$ volts and $E_L = 20$ volts, how will the circuit appear?

a. At resonance.
b. Above resonance.
c. Below resonance.
d. Cannot be determined.

65. (463) What type of coupling would likely be used to couple a high impedance source to a low impedance source or vice versa?

a. LC.
b. RC.
c. RCL.
d. Transformer.

66. (464) The current rating of a tube filament can be increased to match a group of the filaments connected in series by adding a

a. resistor in series with the filament.
b. capacitor in series with the filament.
c. resistor in parallel with the filament.
d. capacitor in parallel with the filament.

67. (465) A diode tube will conduct if the

a. Peak-inverse voltage rating is reached.
b. grid is positive with respect to the cathode.
c. plate is positive with respect to the cathode.
d. plate is negative with respect to the cathode.

68. (466) Triode plate current will *not* be increased by making the

a. grid more positive with respect to the cathode.
b. plate more positive with respect to the cathode.
c. cathode more negative with respect to the grid.
d. plate less positive with respect to the cathode.

69. (467) What causes secondary emission in the tetrode tube?

a. High difference in potential between the screen grid and control grid.
b. Electrons striking the plate and knocking off other electrons.
c. Interelectrode capacitance curve of the tube.
d. Going beyond the peak-inverse voltage rating.

70. (468) In a pentode tube, the supressor grid is located between the screen grid and the

a. cathode, and is connected to ground.
b. plate and is connected to ground.
c. plate, and is connected to the cathode.
d. cathode, and is connected to the cathode.

71. (469) The cathode follower differs from other tube circuits in that the

a. load resistor is in the plate circuit.
b. load resistor is in the cathode circuit.
c. bypass capacitor is in the plate circuit.
d. bypass capacitor is in the cathode circuit.

72. (470) The permissible energy levels of an atom are separated by areas called

a. forbidden energy levels.
b. atomic clearance.
c. covalent bonding.
d. valence shells.

73. (471) When an electron reaches the conduction band, the electron is considered

a. covalent.
b. valence proton.
c. a hole.
d. free.

74. (472) The mobile positive charge that is equal and opposite to the electron's negative charge is called a

a. hole.
b. carrier.
c. free proton.
d. valence proton.

75. (473) What is a crystal called after impurities are added?

a. Intrinsic.
b. Extrinsic.
c. Valence material.
d. Electron-hole pair.

76. (474) In N-type material, electrons are called

a. covalent electrons.
b. valence electrons.
c. majority carriers.
d. minority carriers.

77. (475) What is meant by negative temperature coefficient of a semiconductor?

a. As temperature increases, the resistance of the semi-conductor decreases.
b. As temperature increases, the resistance of the semi-conductor increases.
c. Temperature will not affect the resistance of the semiconductor.
d. As temperature increases or decreases the resistance will increase or decrease respectively.

78. (476) The difference of potential across the depletion region of a junction diode is called the

a. electrostatic field.
b. junction potential.
c. junction barrier.
d. potential hill.

79. (478) Maximum surge current of a diode is the maximum current permitted to flow in the

a. forward direction in the form of recurring pulses.
b. forward direction in the form of nonrecurring pulses.
c. maximum amount of overage which can be permitted to flow in the forward direction.
d. maximum reverse bias voltage which may be applied without causing structure breakdown.

80. (479) What element, if any, of a transistor controls the flow of current carriers?

a. A transistor cannot control its own current carrier flow.
b. Collector.
c. Emitter.
d. Base.

81. (480) In normal operation, the two junctions of a transistor are biased when the emitter-base junction is

a. reverse biased and the collector-base junction is forward biased.
b. forward biased and the collector-base junction is reverse biased.
c. reverse biased and the collector-emitter junction is forward biased.
d. forward biased and the collector-emitter junction is reverse biased.

82. (481) Diffusion is a charge flow caused by

a. the influence of an electric field.
b. the base region being too highly doped.
c. unequal density of charge carriers in a material.
d. excessive current being applied to a transistor in the reverse bias direction.

83. (482) Electrons that have left the emitter and entered the base region become

a. intrinsic carriers.
b. minority carriers.
c. majority carriers.
d. base carriers.

84. (484) What is the signal-voltage phase reversal between input and output of the common-base transistor?

a. Zero.
b. 45 degrees.
c. 90 degrees.
d. 180 degrees.

85. (485) Transistor characteristic curves are

a. used as teaching devices only.
b. oscilloscope waveforms of transistor outputs.
c. graphs plotted to show changing value relationships.
d. the means of selecting the proper replacement transistor.

86. (486) For a given transformer, the output of a bridge rectifier is

a. steadier than the output of a half-wave rectifier.
b. the same as the output of a half-wave rectifier.
c. four times the output of a full-wave rectifier.
d. twice the output of a full-wave rectifier.

87. (487) A multivibrator is capable of producing a

a. nearly rectangular waveform for any desired duration.
b. nearly rectangular waveform for only short durations.
c. sine waveform for any desired duration.
d. sine waveform for only short durations.

88. (488) The output pulses of a one-shot multivibrator are determined by the

a. number of transistors in the multivibrator.
b. frequency of the input pulses.
c. amplitude of the input.
d. polarity of the B+.

89. (489) Refer to figure 8-2 of the text. In quadrants II and III in detail B, the voltage curve is below the baseline as a result of

a. maximum coupling.
b. minimum coupling.
c. the magnetic resolver.
d. a reversal of the rotor.

90. (490) If a cam operated switch remains energized for 50 shaft degrees as specified in the technical order but actuation occurs earlier than specified in the technical order, the *most* likely cause is that the

a. servoslip clutch is set too tightly.
b. phenolic-type material has expanded.
c. cam is not synchronized to its shaft.
d. servometer is rotating faster than normal.

91. (491) One of the uses for a synchro transmitter is to convert

a. electrical signals to mechanical energy.
b. mechanical shaft angles to electrical signals.
c. mechanical shaft angles to mechanical energy.
d. electrical signals to magnetic needle deflections.

92. (491a) Name one type of synchro that provides a mechanical output.

a. Torque rotor.
b. Torque control.
c. Torque receiver.
d. Torque transmitter.

93. (491b) The letter "B" following the specific function designator indicates that the synchro has a

a. rotatable rotor.
b. rotatable stator.
c. stationary rotor.
d. stationary stator.

94. (491c) Coils are shown in the symbol for sychros when the

a. synchro has a rotatable stator.
b. rotor and stator are stationary.
c. stator windings are not separated 120°.
d. the positional relationship between the rotor and stator is important.

95. (491d) Which type of rotor is used in most synchro control transformers and differential units?

a. Wound.
b. Y-connected.
c. Salient-pole.
d. Permanent magnet.

96. (491e) What effect does loading have on an operating synchro?

a. Causes the synchro to generate more heat.
b. Alters the torque gradient of the synchro.
c. Reduces the voltage drop across the windings.
d. Increases current flow through the stator windings.

97. (491f) How do synchros differ from coventional transformers?

a. The synchro windings are fixed.
b. The synchro primary winding can be turned 360°.
c. The synchro secondary windings can be turned 360°.
d. The synchro secondary windings are spaced 180° apart.

98. (491f) The synchro transmitter is in the zero position when the

a. rotor is aligned with the S2 stator winding.
b. rotor is 180° from the S2 stator windings.
c. stator is aligned with the rotor.
d. stator is 180° from the rotor.

99. (491g) What three factors determine the amplitude of the voltage induced into a stator winding of a synchro transmitter?

a. Amplitude of primary voltage, the turns ratio, strength of the magnetic field.
b. The turns ratio, strength of the magnetic field, angular displacement between the rotor and stator windings.
c. Amplitude of primary voltage, the turns ratio, angular displacement between the rotor and stator windings.
d. Amplitude of primary voltage, strength of the magnetic field, angular displacement between the rotor and stator windings.

100. (491h) Why is an extra winding sometimes used in receivers?

a. To prevent overheating.
b. To disperse the magnetic field.
c. To prevent oscillation and spinning.
d. To permit wiring several receivers in parallel.

101. (491i) What electrical relationship exists between the synchro transmitter and receiver when their rotors are in correspondence?

a. Coil voltages are equal and aligned, current is zero.
b. Coil voltages are equal and opposite, current is zero.
c. Coil voltages are equal and aligned, current is maximum.
d. Coil voltages are equal and opposite, current is maximum.

102. (491j) What action is necessary to reverse the rotor's direction of rotation?

a. Swap S1 and S3.
b. Swap S1 and S2.
c. Swap S2 and S3.
d. Swap S2 and S4.

103. (491k) What turns the rotor of a control transformer?

a. Magnetic field.
b. External force.
c. Inertia damper.
d. Hairspring tension.

104. (491l) When a CT is on electrical zero, what is the relationship between its rotor and the S2 windings

a. 120° apart.
b. 270° apart.
c. parallel to each other.
d. perpendicular to each other.

105. (491m) A good way to isolate a problem in an operating synchro system is to use known

a. current as references.
b. voltages as references.
c. resistance as references.
d. mechanical positions as references.

106. (492) What is the radix of a numbering system that uses the symbols -0, 1, 2, 3, and represent numbers?

a. 4.
b. 5.
c. 6.
d. 10.

107. (493) The binary numbering system is widely used with modern computers because

a. when counting in binary, only one digit changes at a time.
b. three octal digits can be converted directly to one binary bit.
c. three digit bits can be directly converted to any decimal digit.
d. the system is most easily represented by bistable electronic devices.

108. (494) Convert $462.40625_{(10)}$ to its binary equivalent.

a. 11011100.10010
b. 101110001.01101
c. 100100111.11101
d. 111001110.01101

109. (495) Convert $244.4375_{(10)}$ to its binary equal.

a. 11110100.0111
b. 10011110.1011
c. 10111100.0111
d. 11010011.1111

110. (496) Convert $10001101_{(2)}$ to its decimal equivalent.

a. 86.
b. 91.
c. 120.
d. 141.

111. (497) Convert $101.101_{(2)}$ to its decimal equivalent.

a. 7.325
b. 6.625
c. 5.625
d. 3.5625

112. (498) Add $11101.1011_{(2)}$ to $1001.01_{(2)}$

a. 100010.1011
b. 101110.1011
c. 100110.1111
d. 101010.1001

113. (499) Subtract $11011.101_{(2)}$ from $100000.110_{(2)}$

a. $110.110_{(2)}$
b. $110.101_{(2)}$
c. $101.001_{(2)}$
d. $100.010_{(2)}$

114. (500) Multiply $1001.101_{(2)}$ by $110.1_{(2)}$.

a. $101010.100_{(2)}$
b. $110011.1101_{(2)}$
c. $110100.1001_{(2)}$
d. $111110.1001_{(2)}$

115. (501) Divide $111110.1001_{(2)}$ by $110.1_{(2)}$.

a. $1101.01_{(2)}$
b. $1011.01_{(2)}$
c. $1001.101_{(2)}$
d. $1011.101_{(2)}$

116. (502) Convert $52.421_{(10)}$ to octal form.

a. $74.3247_{(8)}$
b. $64.3274_{(8)}$
c. $52.3274_{(8)}$
d. $46.4211_{(8)}$

117. (503) Convert $467.65_{(8)}$ to binary form.

a. $100101111.111001_{(2)}$
b. $110100100.110101_{(2)}$
c. $101100111.100111_{(2)}$
d. $100110111.110101_{(2)}$

118. (504) Subtract $35.6_{(8)}$ from $42.5_{(8)}$.

a. $6.9_{(8)}$
b. $5.25_{(8)}$
c. $4.7_{(8)}$
d. $3.8_{(8)}$

119. (505) Convert $427_{(10)}$ to the 8, 4, 2, 1 form equivalent.

a. 010000100111
b. 010010101101
c. 011101110101
d. 100011101101

120. (506) Convert $562_{(10)}$ to the equivalent excess-three code.

a. 100100111101.
b. 100010010101.
c. 10100101101.
d. 110100111001.

121. (507) Convert the Gray code number 1011 to pure binary form.

a. $1011_{(2)}$
b. $1010_{(2)}$
c. $1111_{(2)}$
d. $1110_{(2)}$

122. (508) A binary gate is essentially a

a. switch.
b. flip-flop.
c. storage device.
d. counting device.

123. (509) Of the following statements about inputs to an OR gate which one is correct?

a. If all inputs are binary 0s, the output will be binary 1.
b. If any input is binary 1, the output will be binary 0.
c. If any input is binary 1, the output will be binary 1.
d. If any input is binary 0, the output will be binary 0.

124. (510) The external pulse-shaping network of a single-shot flip-flop that is stable in the SET state determines

a. the toggle frequency of the flip-flop.
b. how long the flip-flop can remain in the SET state.
c. how long the flip-flop can remain in the RESET state.
d. whether the output logic will be positive or negative.

END OF EXERCISE

STUDENT REQUEST FOR ASSISTANCE

PRIVACY ACT STATEMENT

AUTHORITY: 10 USC 8012 and EO 9397. **PRINCIPAL PURPOSES:** To provide student assistance as requested by individual students. **ROUTINE USES:** This form is shipped with ECI course package. It is utilized by the student, as needed, to place an inquiry with ECI. **DISCLOSURE:** Voluntary. The information requested on this form is needed for expeditious handling of the student's need. Failure to provide all information would result in slower action or inability to provide assistance to the student.

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5	Correct SSAN. (List incorrect SSAN here) (Correct SSAN should be shown in Section I)
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7	Request enrollment cancellation. (Justify in REMARKS)
8	Send VRE answer sheets for Vol(s): 1 2 3 4 5 6 7 8 9 Originals were: ☐ Not received ☐ Lost ☐ Misused
9	Send course materials. (Specify in REMARKS) ☐ Not received ☐ Lost ☐ Damaged
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11	Results for VRE Vol(s) 1 2 3 4 5 6 7 8 9 not yet received. Answer sheet(s) submitted ______________ (date).
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AVONICS INSTRUMENT SYSTEMS SPECIALIST

(AFSC 32551)

Volume 4

Maintenance Fundamentals and Engine Instruments

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UNITED STATES OF AMERICA

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THIS PUBLICATION HAS BEEN REVIEWED AND APPROVED BY COMPETENT PERSONNEL OF THE PREPARING COMMAND IN ACCORDANCE WITH CURRENT DIRECTIVES ON DOCTRINE, POLICY, ESSENTIALITY, PROPRIETY, AND QUALITY.

Preface

THIS IS THE fourth volume of the *Avionics Instrument Systems Specialis* course. The value of Volume 4 can be stated by saying that the material covered is confined to your career field.

In Chapter 1 you will study the fundamentals of avionics instrument systems maintenance. Chapter 2 starts you on the simplest basic instruments— direct reading pressure gages. Chapter 3 builds upon those basic instruments by taking you through represenative synchro and variable reluctance systems. Chapter 4 covers thrust measurement systems. Chapter 5 deals with tachometers and temperature indicating systems. Chapter 6 explains how the measurements covered in Chapters 2 through 5 are sometimes displayed on moving tapes invertical scale engine instrument systems.

Illustrations are provided to clarify the text. Code numbers appearing on the figures are for preparing agency only and should be of no concern to the student.

Direct your questions or comments relating to the accuracy or currency of this volume to the course author: 3360 TCHTG/TTGU-F, ATTN: MSgt Lawrence B. Miller, Chanute AFB IL 61868. If you need an immediate response, call the author, AUTOVON: 862-2041, between 0800 and 1600, Central Standard Time, Monday through Friday.

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If you have questions on course enrollment or administration, or on any of ECI's instructional aids (Your Key to a Successful Course, Behavioral Objective Exercises, Volume Review Exercise, and Course Examination), consult your education officer, training officer, or NCO, as appropriate. If this person can't answer your questions, send them to ECI, Gunter AFS AL 36118, preferably on ECI Form 17, Student Request for Assistance.

This volume is valued at 42 hours (14 points).

Material in this volume is technically accurate, adequate, and current as of July 1981.

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CHAPTER 1

NOTE: In this volume, the subject matter is developed by a series of Learning Objectives. Each of these carries a 3-digit number and is in boldface type. Each sets a learning goal for you. The text that follows the objective gives you the information you need to reach that goal. The exercises following the information give you a check on your achievement. When you complete them, see if your answers match those in the back of this volume. If your response to an exercise is incorrect, review the objective and its text.

Maintenance Fundamentals

AS AN avionics instrument specialist, you know that the maintenance of instruments and related equipment is the major part of your job. This includes the fundamentals of the inshop repair of those instruments, as well as systems maintenance on the aircraft.

1-1. General Maintenance Procedures

The safe operation of any aircraft is dependent upon its instruments. Without these delicately calibrated and properly maintained mechanisms, it would be impossible to safely operate modern vehicles of flight. In this section, you will study the fundamentals of maintaining these instruments and instrument systems.

600. Given a list of conditions for packaging, labeling, and conditioning instruments, match each with the proper definition or explanation.

Supplies and equipment that are procured to support military actions must be protected from deterioration and damage in order to be in a serviceable, ready-to-use condition at the time and place of need. Our instruments are becoming more complex; therefore, they are more sensitive to damage due to mishandling, improper packaging, and shock. This, coupled with their high cost, means that everyone involved in their use must use every precaution to prevent damage to them.

Packaging and Labeling Instruments. For storage and handling, all items of Air Force equipment are packaged and labeled. Every instrument received from supply should be in a protective container. The type of equipment, the shipping destinations, and the storage consideratins determine the type of container and packaging and packing level used. These levels are defined in AFR 71–6, *Packaging of Materiel*.

Level A (military package) protects against corrosion, deterioration, and damage during shipment, handling, storage, and worldwide distribution.

Level B (limited military package) is developed as a modification of the military package or as a separate type for use under specific conditions. This type of packing protects instruments against damage during multiple shipments and while they are in storage.

Level C is not *commercial packaging*. Commercial packaging eliminates the required materials. It may satisfy Level A or Level B requirements; however, it is intended for use in shipments to the first destination for immediate use.

Levels A and B packaging is normally intended to be reused. These containers are constructed under a specific transportation packaging order (TPO). TPOs include details for blocking, bracing, cushioning, shock mounts, tiedown devices, and special-purpose containers as required to protect items that require special preservation and packaging. To assure the continued serviceability of the instruments, to avoid needless labor and material costs, and to avoid solid waste disposal problems, the reusable container—which is designed for the return of reparable items and for reshipment of serviceable items—must in fact be reused; so, save it.

Instruments should always be shipped or transported in the complete, original shipping container, and the original cushioning material should be used. Replacement, removed, or reparable instruments should be moved between supply, the maintenance shop, and the aircraft in the complete container. A defective instrument should be handled with the same precautions as new or serviceable instruments to prevent damage. Only one instrument should be packaged in a container. Plug or cover all openings and female electrical connectors before the instrument is packaged to keep moisture, dust, and other foreign objects out of the unit.

Instruments classified as dangerous or hazardous because they contain magnetic or radioactive material must be shielded, packaged, or otherwise protected and marked before they can be shipped on military aircraft. Also, all serviceable and reparable fuel systems instruments, capable of holding flammable fuel, must be drained and flushed and all their openings sealed with the correct plugs or caps, as specified in the applicable field or overhaul technical manual. A list of plugs and caps can be found in TO 6J3–1–1. Compliance with these provisions must be annotated on the accompanying paperwork, such as AFTO Form 350, Reparable Item Processing Tag; condition tags; and labels.

When you package an instrument, you must also provide the necessary maintenance documentation, item identification, marking, and label. Mark and labeling as required by TO. All material defined as hazardous by AFM 71–4, *Preparation of Hazardous Materials for Military* by marked as required by AFM 71–4. Also apply precautionary markings such as "Fragile Instrument - Handle with care," etc.

The container must have a tag or label attached showing what the unit is and its condition. The condition can easily be determined when the proper colored tag is attached: a yellow tag shows that the item is serviceable, a green tag shows that the item is in need of repair, and a red tag shows that the item is no longer worth repairing and is condemned.

Exercises (600):

1. List three causes of damage to sensitive instruments.

2. What determines the type and level of packing used for an instrument?

3. Match the conditions listed in column A with the correct response in column B by writing the correct letter in the space provided. Since there is only one response for each condition, some of the choices in column B will not be used.

Column A	*Column B*
____ (1) Military package for worldwide shipment.	a. TPO packages.
____ (2) Limited military package for storage.	b. Commercial packaging.
____ (3) Minimum package for immediate use of the first receiving activity.	c. Protection from moisture, dust, and foreign objects.
____ (4) Reuseable containers.	d. Level A packaging.
____ (5) Plugs, caps, and covers.	e. Level B packaging.
____ (6) Plugs and caps listing.	f. Field level.
	g. TO 6J3-1-1.
	h. Depot level.
	i. Protection from accidental explosions.

601. Define common terms and specify procedures in the removal and replacement of instruments and instrument systems components.

Removal and Installation of Instruments. When removing and replacing an instrument for any reason, replace it with a like, interchangeable, or suitable substitute instrument. By like item, we mean exactly the same item as specified in the TO. An interchangeable item is different but so similar that either may be used in place of the other. A suitable substitute is a similar item which meets or exceeds the requirements of the original item, but they are not interchangeable because the original item will not do the job of the substitute item.

Remove the installed indicator by removing the mount screws, using the proper type and size of screwdriver. One of two types of mounting methods may be encountered. They are bezel mounting and clamp mounting. The standby compass in figure 1-1 is a bezel- mounted instrument. The type of instrument shown in figure 1-2 is normally clamp mounted; however, you can install a bezel mount as shown in figure 1-3.

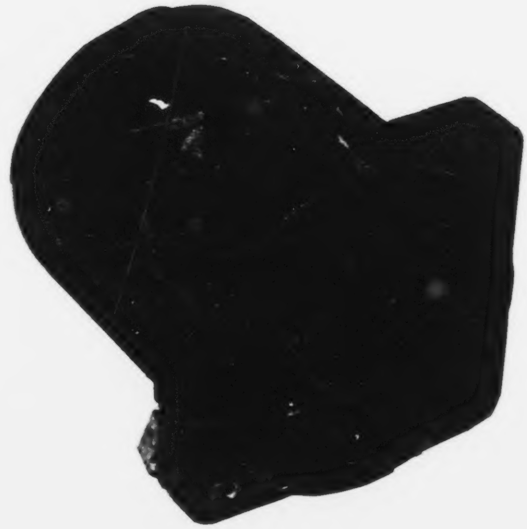


Figure 1–1. Bezel-mounted instrument (standby compass).

The bezel of an instrument is the flanged part that holds the cover glass in place. On some indicators, like the standby compass, the bezel and mount are one piece. On others, the bezel mount is removeable. When a bezel mount is used, the indicator can be mounted either from the front of the instrument panel (see fig. 1-4, or from the rear of the panel. The forward edge of the instrument has a flange around it. The bezel rings rings come in two parts (see fig. 1-3) and are attached to the case by means of this flange. One part is slipped over the case from the rear until it meets the flange. Then, the second part is attached to the front by means of bezel screws.

Bezel mounting from the front makes the instrument easier to remove and install. This is the type of bezel mounting most used. In this type of mounting, the connections to the instrument are made before it is inserted into the panel cutout. The instrument is then inserted in the panel so that the bezel is on the cockpit side of the panel. It is then fastened in place with the mounting screws.

Bezel-type mounting from the rear is seldom necessary. If required, the instrument is placed in the cutout from the

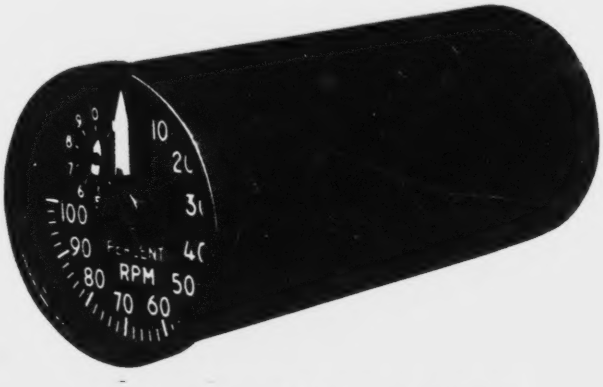


Figure 1–2. Clamp-mounted instrument (tachometer).

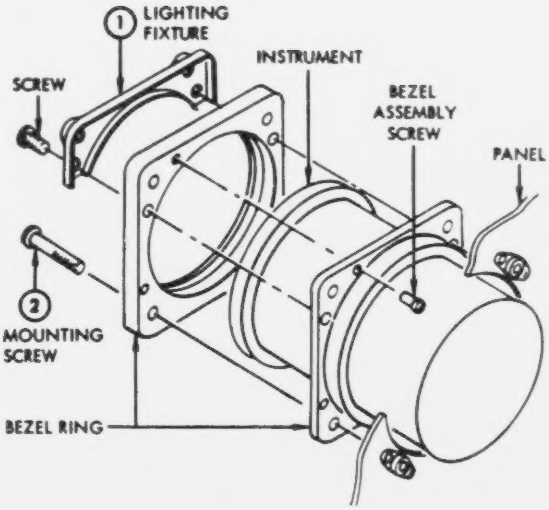


Figure 1-3. Installation of a bezel mount.

back of the panel. Mounting screws are then inserted from the front. This method may require two people, one to hold the instrument in place and the second to install the screws from the front.

You should always use new screws when installing bezel-mounted instruments because the instrument screws are made of brass and are easily damaged. Be careful not to damage the threads or deform the screwdriver slots when installing these screws so that they will be easy to remove when necessary. Dispose of the old screws in the proper trash receptacle so that they will not present a FOD hazard.

When the bezel mount is not used, a clamp fits around the instrument case, as shown in figure 1-5, to hold the instrument in the panel. The clamp is mounted to the back of the panel by one screw, which is usually located at the upper left-hand corner of the panel cutout, as shown in figure 1-6. The instrument is then inserted from the front of the panel. The clamp is drawn tight by means of a second, larger screw, which is usually located at the lower right-hand corner of the cutout. One advantage of clamp mounting is that you can install the instruments so that, under normal operating conditions, all of the pointers will line up in the same direction.

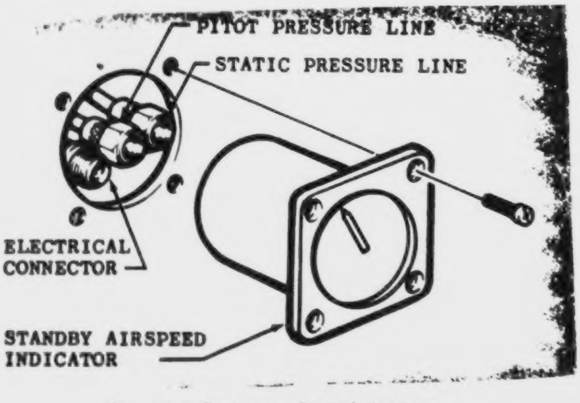


Figure 1-4. Front-mounting an instrument.

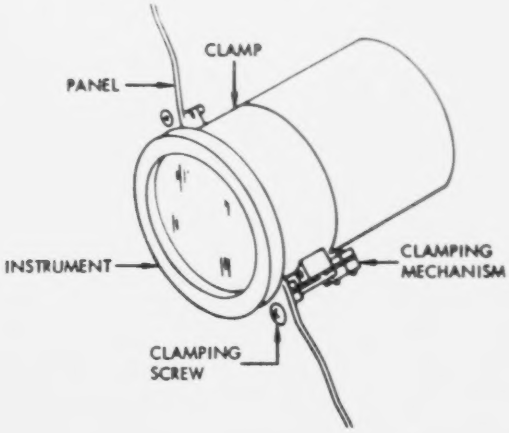


Figure 1-5. Installation of an instrument clamp.

Before installing any item, inspect its mount and the area around it for any obvious fault which might be hidden with the unit in place. Make sure the area is clean and free of debris. Inspect the mating connectors for contamination and corrosion or otherwise damaged fittings, pins, or sockets.

If completion of the job is delayed for any reason, do the following to eliminate the possibility of electrical shorts or damage to loose connections:

- Pull the system circuit breakers and tag them with AF Forms 1492, Danger.
- Cover the open ends of loose electrical connections to prevent anything that could short the pins from entering. If there is a possibility that they could get wet, cover them with plastic bags.
- Anytime a component is disconnected in a pitot or static system, cap or plug all exposed openings to prevent entry of dirt and moisture.
- Cap or plug open fuel, oil, and hydraulic lines, and place a danger tag in the cockpit on the system's operating controls.
- When you remove a component and install protective caps, enter all pertinent information in the next open discrepancy block of the AFTO 781, Aerospace Vehicle Flight Data Document, on a red X symbol. This pertinent information includes the location of all plugs, caps, and danger tags.

TOs 1–1A–8, 1–1A–14, 6J3–1–1, and 42E1–1–1 contain information on the different types of plugs and caps available.

After you install a component, perform an operational check of the system. This is required by TO 1–1–300, which states:

> a. Maintenance operational checks will be accomplished on the ground to assure that aircraft systems, or components, which have been disturbed during inspection or maintenance operations, have been repaired, reassembled, or adjusted satisfactorily.
>
> b. These checks will be accomplished in such a manner as to simulate, insofar as possible, the conditions under which the system, or component, will be operated during takeoff, flight, and

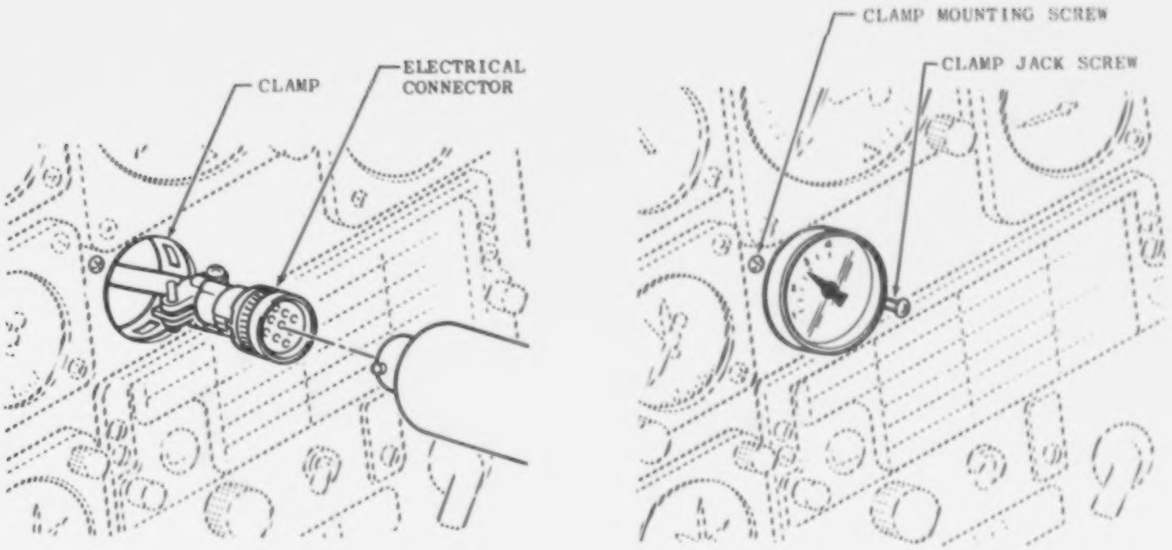


Figure 1-6. Clamp-mounting an instrument

landing. The affected equipment will be operated sufficiently to assure that the aircraft is safe for operational use.

These operational checks must be recorded on the AFTO Form 781A and on your AFTO Form 349, Maintenance Data Collection Record.

Exercises (601):

1. Differentiate between an interchangeable item and a suitable substitute item.

2. What is the bezel of an indicator?

3. What type of instrument mounting must be done from the front?

4. What should you do before you install any instrument?

5. If you remove an indicator and do not immediately reinstall a like item, what should you do about the loose electrical connector on the aircraft?

6. List four actions you should take if you open a fuel line for removal of a fuel flow transmitter.

602. State the methods used by instrument personnel to help the aircrew determine if flight operations are safe, desirable, or unsafe.

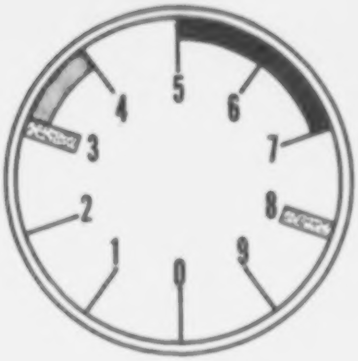
Application of Range Marks. Either prior to installation or immediately after installation, apply the necessary range marks to those instruments requiring them. The exact ranges to be covered on each instrument for a given aircraft can be determined only through reference to the instrument marking instructions of the appropriate aircraft -1 TO, which is the flight manual.

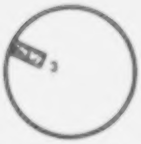
Instrument range or limit markings are applied to indicate to the aircrew, at a glance, that flight operations are safe, desirable, or unsafe. As described in TO 5-1-2, the instrument range marking system consists of four colors and intermediate blank spaces (areas not range marked): RED is used to indicate a dangerous condition which will require specific action by the aircrew; GREEN indicates a safe condition, normal operating range; YELLOW indicates an unsafe or undesirable condition. Limited operation is permissable on YELLOW as directed by the applicable flight manual; BLUE relates to fuel mixture and denotes lean operating conditions.

Range markings are decals that are normally applied to the glass directly over the instrument graduations of the scale ranges, as shown in figure 1-7. However, if in this position the markings should interfere with instrument readings from the normal crew position, you may move them above or below the graduations as required. Be sure the markings cover the correct range.

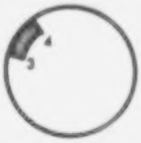
Clean the surface on which the marker is to be placed. Be sure that there is no oil or grease film on this area since the marker will not stick under these conditions. Cut the material to size and remove the backing material before application. This pressure sensitive material requires no curing time, but adhesion does improve with age.

A slippage mark must also be applied to all instruments which have range markings on the cover glass. This is a

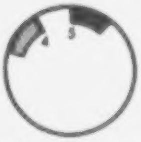




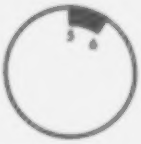
(Danger) Red radial at 3.— A dangerous condition exists if the pointer is ever below this marking during flight.



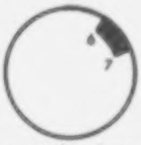
(Caution) Yellow arc from 3 to 4.— Indicates that danger may exist under certain conditions.



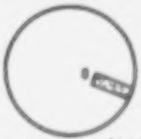
(Undesirable) Blank space from 4 to 5. — Indicates region that should be avoided or region in which operation is limited.



(Auto-lean) Blue arc from 5 to 6. — Indicates auto-lean operation is permitted.



(Desirable or auto-rich) Green arc from 6 to 7— Indicates region for continous operation. When used in conjunction with blue markings, green takes on a special meaning requiring auto-rich operation when the pointer is in this region.



(Danger) Red radial at 8. — Operation above this value is prohibited.

Figure 1-7. Application of range marks.

white index mark not over 1/16-inch wide which is painted on the instrument glass and extended onto the instrument case or bezel mount. It should be placed across the joint between the glass and the case at the bottom (6 o'clock position) or in an uncalibrated area. This mark will show if the cover glass has shifted. Any difference between the part of the index (slippage) mark on the glass and the part on the case will reveal any errors in the location of the range markings. Many of the instruments used in today's aircraft are hermetically sealed, some are square shaped with crescent glass, and some are vertical scale type instruments. It would be difficult for properly installed instrument glass to slip on these instruments. The flight crew, however, should not have to determine if it is possible if the glass in these types of instruments could have slipped. Therefore, the rule is, "If the instrument has markings on the glass, it will also have an index mark."

Instruments that have a calibration screw (zero setting) on the face of the instrument must have a white line marked across the screw onto the case of the instrument. This mark is used to indicate any movement of the calibration screw after calibration. Indicators requiring a calibration screw marking include vertical velocity indicators and some temperature indicators.

TO 5-1-2 contains more detailed information on range-marking different types of indicators, as well as a list of applicable materials to be used.

Exercises (602):

1. What is the purpose of instrument range or limit markings?

2. List the colors used in the range marking of instruments, and give their meanings.

3. Where on the instrument are range markings normally applied?

4. What will prevent range markings from sticking to the glass?

5. On which instruments are slippage marks used?

6. What is the purpose of the 1/16-inch wide white markings on the cover glass of an instrument?

603. State the most common means of securing aircraft instrument systems components and their connections.

Lockwiring. Safetying is an important part of instrument systems maintenance. Aircraft vibration tends to loosen or alter the adjustment of various parts. These may be nuts, bolts, turn-buckles, screws, electrical connectors, pressure lines, etc. These parts, which may require frequent removal, disassembly, of adjustment, are normally secured by an auxillary device. Safety wire, often called lockwire, is the most commonly used securing device.

Safety wire is available in .020-inch diameter copper wire, .031-inch diameter aluminum wire, and carbon steel corrosion resistant steel, monel (a nickel and copper alloy), and iconel (a nickel, chrome, and iron alloy) in sizes from .020-inch to .047-inch in diameter. Each type and size is intended for specific uses, as described in TO 1-1A-8, TO 1-1A-14, and applicable systems technical manuals.

For example, copper wire is frequently used for sealing such equipement as first aid kits, portable fire extinguishers, covers on emergency switches, etc. Aluminum wire is normally used for safetying equipment like emergency valves and oxygen regulators. These types of wire can be easily broken and are primarily used as seals. When broken, they show that the equipment was used or tampered with.

For securing equipment, use zinc-coated soft steel wire; but where nonmagnetic qualities and heat-resisting properties are required, use annealed (toughened or strengthened) corrosion resisting wire. Be careful not to confuse aluminum wire (.031-inch diameter) with .032-inch diameter steel wire.

Safetying rules. When you have determined what type of wire to use, be sure to select the correct size. The safety wire used should normally fill at least three-fourths of the hole.

Use only new safety wire. Be sure that the wire does not become kinked or nicked during the twisting operation and that the plating on the wire is not damaged. If the wire does become damaged, start over again with a new piece. In an attempt to align holes for safety wiring, do not back off or overtorque mounting screws, bolts, or nuts.

Safetying methods. There are two methods of applying safety wire: the single-strand and double-twist methods. The single-strand method is used on screws in a closely spaced or closed pattern like a triangle, square, rectangle, or circle. This method may be used on parts of the system in places that are difficult to reach (see fig. 1-8). The maximum number that may be safetied together with a single strand of wire is limited to the number which a 24-inch long piece of wire will reach.

In the double-twist method, the wires are twisted together to form a double-strength safety. The wires should be twisted right handed approximately 8 to 10 times per inch to produce a tightening effect. Your shop may have special pliers for safetying. If not, the wires must be twisted by hand. Use duck bill pliers for the last few twists to apply the proper tension and to properly secure the ends. When using either method of safetying, the ends of the wire should form a pigtail 1/4- to 1/2-inch long. Always be sure that you bend back the pigtail when finished. This will save you and the next person from painful cuts and scratches on the sharp wire ends. Always make sure that your safety wire pulls in the direction that will tighten the nuts, bolts, screws, or

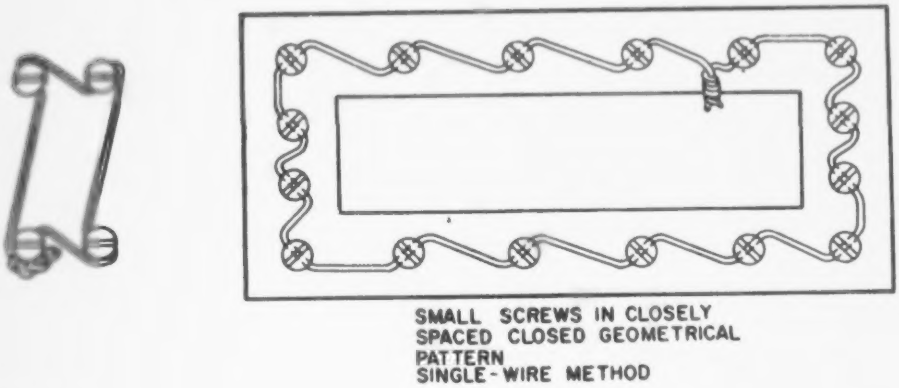


Figure 1–8. Single-strand method of safety wiring.

other device being safetied. When using the double-twist method, the maximum number of bolts that may be safetied together is three, as shown in figure 1-9, along with other examples of the double-twist method.

All electrical connectors, unless mechanically locked or treated as otherwise specified, must be safety-wired to prevent opening of the connection due to vibration. Connectors located on shock-mounted units in a pressurized compartment need not be safety-wired unless specifically required by component installation instructions. Always use the double-twist method for connectors, as shown in figure 1-10. Use new corrosion resistant wire of .020-inch diameter on electrical connectors, and under no circumstances should you safety an electrical connector to a fuel, oil, hydraulic, or oxygen line.

Other safetying or locking devices. Under some conditions, safety wire cannot be used to secure fastening devices. Cotter pins, retaining pins, lockwashers, or checknuts, as shown in figure 1-11, may be required by technical data.

Exercises (603):

1. What size safety wire is used to secure electrical connections?

2. What type of wire is used to seal emergency equipment? Why?

3. Where is the single-strand method of safetying used?

4. What is the maximum number of screws that may be safetied together using the single-strand method?

5. What is the double-twist method of safetying?

6. When you finish your safetying job, what two things should you recheck to see if you have done it correctly?

604. Define bonding and state bonding requirements for different types of instruments.

Bonding. Bonding is the electrical connection of two or more conductive surfaces that are not otherwise adequately connected. All electrically-operated instruments should be bonded to obtain a low resistance of .1 ohm maximum. This is to eliminate any difference in potential. It provides a direct path to ground for current flow.

Clamp-mounted instruments are bonded by removing a small area of the protective finish from the case between the case and the clamp. The clamps should be bonded to the panel. All bezel-mounted instruments, with a few exceptions, are bonded at the upper right mounting screw. Bezel-mounted instruments are bonded by spot cleaning the contact surfaces between the mounting screw and light fixture (if used), between the light fixture and case, and between the instrument panel and nut. Instruments without electrical connections have no bonding requirements and should not have the protective finish removed unless there is a specific requirement.

Shock-mounted components are bonded to the shock mounts. The shock mounts have bonding jumper wires which connect to the airplane structure. To insure a good connection, the terminal ends and the structure surface they attach to should be kept clean and bright. Always check your TO for bonding requirements.

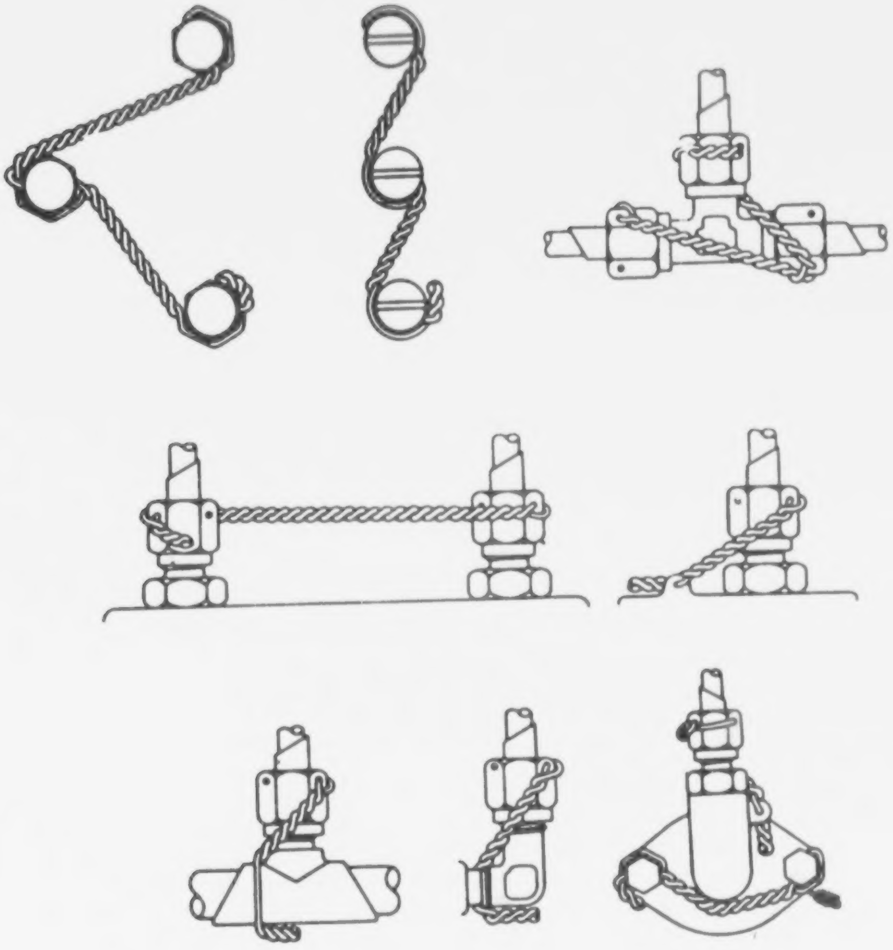


Figure 1–9. Double-twist method of safety wiring.

Exercises (604):

1. Define bonding. Why is it done?

2. How are clamp-mounted instruments bonded?

3. How are bezel-mounted instruments bonded?

4. How are shock-mounted instruments bonded?

605. State the different phases in the repair of instruments.

Repairing Instruments. Instrument overhaul manuals are issued to serve as the basic instructions covering the disassembly, inspection, replacement of parts, necessary repairs, reassembly, calibration, sealing, and testing of instruments. Most of these manuals are a series of steps by which the instrument parts are replaced or repaired. Instrument repair is basically the replacement of defective parts and assemblies; nevertheless, the repair of parts and assemblies is desirable and can be done. This repair should be made even on expendable unserviceable items when the inspection of the item shows that it could be repaired using stand when are shop practices and repair parts are available.

If all repair procedures were followed on an instrument, the whole instrument would have to be disassembled down to the last screw or bolt and each part would have to be inspected, repaired or replaced, and reassembled.

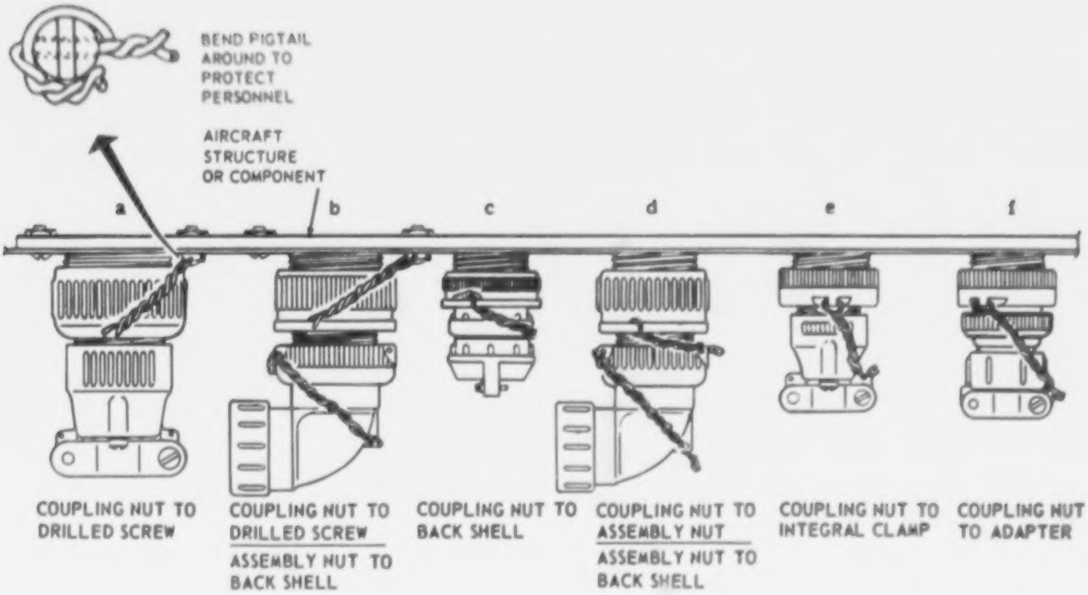

BEND PIGTAIL AROUND TO PROTECT PERSONNEL
AIRCRAFT STRUCTURE OR COMPONENT
a
b
c
d
e
f
COUPLING NUT TO DRILLED SCREW
COUPLING NUT TO DRILLED SCREW
ASSEMBLY NUT TO BACK SHELL
COUPLING NUT TO BACK SHELL
COUPLING NUT TO ASSEMBLY NUT
ASSEMBLY NUT TO BACK SHELL
COUPLING NUT TO INTEGRAL CLAMP
COUPLING NUT TO ADAPTER

Figure 1–10. Safety wiring electrical connectors.

Experience has proven, in most cases, that this repair concept is wasteful; therefore, a "selective repair" standard is used. This means that repairs to most instruments will be limited to those repairs determined necessary by inspection and testing.

In addition to specific instrument technical manuals, other 5–5–TOs that apply to instrument repair include TO 5–1–1, TO 5, TO 5–1–10, TO 5–1–16, TO 5–1–17, TO 00–25–203, and TO 00–25–234. Each person repairing instruments should be familiar with these general TOs. Should there be a conflict between a general TO and a specific instrument TO, the specific instrument TO is the one to use.

All activities performing instrument maintenance should understand that the ability of AFLC to increase the reliability of instruments depends directly upon valid data's being furnished through the maintenance data collection system. Proper entries on AFTO Forms 349 and 350 greatly help management people to track instrument performance. Accurate and complete data is especially important for the development of instrument improvement projects.

The USAF concept of instrument repair consists of inspecting each instrument to determine its general condition, including removing the case or cover and inspecting the internal mechanism of nonhermetically sealed instruments. This inspection also includes checking for external damage and the need for cleaning. The appearance must be neat but does not have to be like new. Minor visual defects that do not affect serviceability do not require repair work. Also check for any unaccomplished

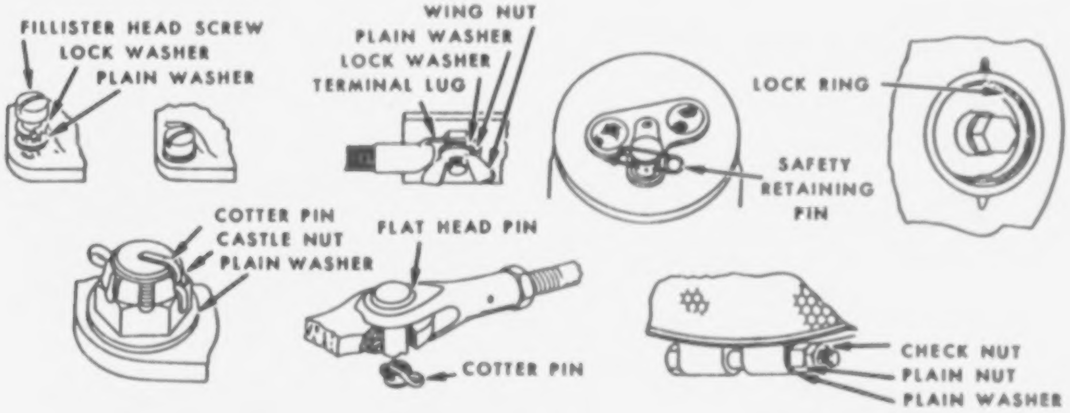

FILLISTER HEAD SCREW
LOCK WASHER
PLAIN WASHER
WING NUT
PLAIN WASHER
LOCK WASHER
TERMINAL LUG
LOCK RING
SAFETY RETAINING PIN
COTTER PIN
CASTLE NUT
PLAIN WASHER
FLAT HEAD PIN
COTTER PIN
CHECK NUT
PLAIN NUT
PLAIN WASHER

Figure 1–11. Hardware locking devices.

TCTOs or modifications. All items or components showing evidence of corrosion should be processed in accordance with TO 5-1-17.

Instruments that have passed the physical inspection should then be functionally checked using the final tests in the overhaul manual for that instrument, including any required calibration. Instruments that pass all inspection and functional test requirements should be accepted as serviceable unless the TO specifies exceptions.

If the inspection reveals defects, the instrument fails to pass the functional test, or the instrument needs modification the instrument must be repaired. This repair will require disassembly of the instrument only to the extent needed to determine the failure cause or condition. Once the defects have been identified, do only the essential repairs and/or modifications to produce a serviceable instrument.

After the necessary work has been done, reassemble and test the instrument as prescribed in the applicable technical manual. A repaired unit must pass all of the final functional tests listed in the technical manual before it can be certified as a serviceable unit.

Parts worn or damaged beyond repair will be condemned. Parts replaced as a result of a modification will also be condemned, unless otherwise directed. When a number of reparable instruments are waiting for parts which are not immediately available, some of those instruments should be used to provide the parts needed to repair the rest of those instruments. Normally, when any one instrument requires enough parts and labor to equal 75% or more of its original cost, it must be condemned.

Cleaning Instrument Parts. TO 5-1-10 provides specific guidance for the use of cleaning solvents for instrument equipment. It is impossible to maintain close tolerances on instruments without their being very clean. Cleanliness often means the difference between good and bad instruments. Cleaning includes the removal of oil film from the jewels, bearings, gear teeth and plates, and springs. It also includes the removal of dirt and dust from the instrument. Over a period of time, instrument oil combines with oxygen in the air to form a scum that can be removed by cleaning. Considering the requirements imposed on the Air Force by OSHA, the procedures in TO 5-1-10 may be used in lieu of those in the basic instrument repair manual.

The use of instrument cleaning solvents must be limited to the brush and dip methods in order to eliminate direct contact of the solvents with your skin. Adequate ventilation must be available as prescribed in AFOSH Standard 161-2, Precautionary Measures for Handling Solvents, anytime such solvents are being used. Supervisors and repair personnel need to work closely with the ground safety, medical bioenvironmental, and industrial waste treatment offices to insure the use of proper safety controls and precautions.

Exercises (605):

1. When should expendable unserviceable items be repaired?

2. What the concept of selective repair?

3. What are the four phases in the USAF concept of instrument repair?

4. What is the status of parts replaced as a result of a modification?

5. How does the cost of an instrument determine whether or not it should be repaired?

6. How do OSHA requirements affect the repair of instruments?

606. Identify types of corrosion, corrosion prevention methods, and treatments for corrosion.

Corrosion Control. TO 5-1-17 furnishes instrument overhaul activities with instructions on how to control and treat corrosion encountered during the repair of instruments. Materials, particularly metals, used in the manufacture of instruments and instrument parts are subject to corrosion.

Corrosion is the gradual chemical or electrochemical attack on a metal by atmosphere, moisture, or other agents. Galvanic corrosion occurs when two dissimilar metals with different solution potentials are in electrical contact in the presence of an electrolyte; the electrolyte is usually supplied by contaminated atmospheric moisture. This type of corrosion appears as a salt formation which, when removed, reveals a pitted metal surface. Fretting corrosion appears at the joint of two contacting surfaces which, if subject to vibration, becomes deformed.

Destruction of metals by this slow process of chemical decline (corrosion) occurs because most metals tend to convert back to their natural states, such as oxides (rust), hydroxides, sulfates, etc. The extent of this corrosion is directly dependent upon the type of metals and the environment to which they are subjected.

Parts affected by corrosion should be either replaced or reworked. Replace them if the corrosion and treatment affects size tolerances or the function of the part; otherwise, rework the parts and return them to service. The function of a part is an important factor in determining if a corroded part can be used. Cleaning corrosion from parts that require lic fits or balances could affect the accuracy of the instrument. Such parts must be replaced. However, housings and other nonsensitive parts can withstand much corrosion cleaning and reworking before becoming weak or out of size. Regardless of where corrosion has taken place, it must be removed to prevent further deterioration, flaking, and possibly lodging in critical areas.

Wire, washers, nuts, bolts, lock washers, bearings and pivots must be replaced if corroded. So must fuse clips, tube sockets, tube pins, and cable connectors. Switches, brushes, slip rings, commutators, and other electrical contacts that cannot be cleaned using an appropriate contact cleaner must be replaced. They should never be scraped clean. Threaded parts and tapped holes must be replaced if size and fit is affected by cleaning. Tapped holes can be cleaned by inserting the proper size tapping tool. Seals, such as "O" rings, must always be replaced regardless of condition.

Stainless steel and nickel-chrome alloys are resistant to corrosion. They can normally be reused. Aluminum ordinarily provides its own thin protective oxide coating. However, certain conditions can prevent formation of this coating. The presence of excessive corrosion indicates the need for additional protective treatment, such as painting or anodizing. Copper and copper-base alloys resist atmospheric corrosion; however, the green patina often found on copper is evidence of corrosion. It is usually very thin and offers protection from further corrosion. If it is objectionable, TO 1–1–2 has instructions on its removal and treatment. This TO contains general information and instructions for every type of metal and corrosion encountered in aircraft maintenance.

Corrosion is not limited to instruments and instrument parts. The nature of corrosion requires that everyone involved in the building, operational use, or maintenance of aerospace equipment (aircraft and all other equipment) be concerned with corrosion prevention and control. Everyone must be aware and concerned with safety, cleanliness, work habits, and work methods. Remember the following factors while performing routine duties:

a. Check with supervisors prior to using certain types of materials or mechanical procedures in situations that are unfamiliar.

b. Keep work areas, equipment, and components clean. Chips, grit, dirt, and foreign materials must be moved.

c. Do *not* use graphite pencils on any metal surface. This also applies to any sharp-pointed objects. Special pencils for this purpose are available in red, yellow, and black.

d. Do *not* use graphite lubricants. They set up conditions for galvanic corrosion in a hot, moist environment.

e. Wear only approved footwear when it becomes necessary to walk on aircraft surfaces such as wings, stabilizers, fuel tanks, etc. Insure that no metal chips, stones, dirt, sand, etc., are lodged in your footwear or clothing prior to walking or working on these areas.

f. Do *not* scratch any surface unless it is an authorized procedure. If you accidentally scratch any surface, see that qualified personnel assess the damage and take action to remove the scratch and treat or replace the component. Use extreme care with toolboxes, and components around aircraft to avoid damaging the painted finishes.

g. When welding, grinding, drilling, etc., cover the surfaces of the surrounding equipment. Remove the residue from these operations immediately if protective measures cannot be used easily.

h. Most important, during the course of your routine repair work, report frequent, severe, or unusual corrosion to the corrosion control supervisor or specialist. Do not ignore the corrosion, thinking that it's not bad enough to bother with or that someone else will surely take care of it. Corrosion control is everyone's responsibility.

Exercises (606):

1. Define corrosion.

2. What should be done about parts affected by corrosion?

3. Give three reasons why corrosion in instruments should be removed.

4. What method should never be used to remove corrosion from electrical contacts?

5. Who is responsible for the control and prevention of corrosion?

6. What should you do if you are in doubt about a procedural task and are unsure of the results?

7. What type of pencils are not authorized for marking on metal surfaces?

8. Galvanic corrosion may be the result of heat, moisture, and what type of lubrication?

9. What two factors must you consider prior to walking on aircraft exterior surfaces.

10. If you scratch the painted surface of an aircraft with your toolbox, what action should you take?

11. When welding, drilling, or grinding, how can you protect surrounding surfaces?

12. Who is responsible for reporting frequent, severe, or unusual

Direct Reading Pressure Gages

IN THIS CHAPTER we discuss the most commonly used pressure-sensing devices found in direct reading pressure gages. You will learn how to inspect, operationally check, troubleshoot, bench check, and calibrate direct reading pressure gages. You will also learn the types of pressure gages and the types of pressures measured by these gages. The most important part of a direct reading pressure gage is the pressure-sensing device.

2-1. Pressure-Sensing Mechanisms

Most pressure-sensing devices are forms of metal containers that will expand, contract, or straighten out when pressure is applied to them. This pressure may be applied either internally or externally.

Direct reading pressure gages fall into two categories. They are *absolute* pressure or *differential* pressure-measuring gages. An absolute pressure-measuring device shows the pressure above a zero reference point (perfect vacuum). The differential pressure-measuring device shows the pressure above or below a reference point. This reference point is usually atmospheric pressure. There are four sensitive elements used to measure these pressures. They are the bourdon tube, the diaphragm, the bellows, and the aneroid.

607. Specify the operational characteristics and use of the bourdon tube sensing mechanism.

Bourdon Tube. The bourdon tube is the basic mechanism of high-pressure indicating instruments. It can be found in oil, hydraulic, and oxygen pressure gages. It was designed some hundred years ago by a Parisian named Eugene Bourdon. He applied some internal pressure to a coil of flattened copper tubing to restore its cylindrical form. He found that, as the tubing was made round again by the pressure, it also uncoiled. Further experiments showed him that the amount that the tubing uncoiled was in direct proportion to the amount of pressure applied. This is the principle of operation of the bourdon tube.

Study the bourdon tube shown in figure 2-1. Notice that one end of it is rigidly fastened to the intake socket. The other end has an eyelet by which it is attached to the hinged link. When pressure is applied into the tube, the outward movement of the tube pulls the hinged link in the direction of the arrow. This motion is transmitted to the sector gear which rotates the pinion, and the attached pointer moves across a graduated scale. The combined movements show an increase in pressure. The hairspring takes up the backlash between the components of the mechanism. Stop screws (fig. 2-2) are arranged around the bourdon tube to stop its motion when full-scale deflection is reached.

The operation of the bourdon tube is based on its springlike qualities and on the fact that it will straighten out when internal pressure is applied. The internal pressure is partially offset by the atmospheric pressure applied to the outside of the tube. Thus the gage is a differential pressure-measuring device. It measures the difference between two pressures. The tube will always return to its normal position when pressure is released. The movement of the tube is proportional to the amount of difference in pressure. This causes the movement of the link, sector, and pinion, shown in figure 2-3A. The sector gears are referred to as the movement (C) in figure 2-3B. This principle of operation applies to all bourdon tube devices. The difference between bourdon tubes is in the wall thickness and stiffness of the tube itself. Naturally, if the range of an instrument is increased, a heavier bourdon tube must be used.

A dual bourdon tube device is used in some gages where the gage is to be installed in a pressurized cabin. The mechanism is housed in an airtight case. This differs from the single-tube mechanism. The single-tube device is housed in a case that is vented by a drain hole in the bottom of the case. The single-tube gage is used in aircraft that are not pressurized. Let's say that you wanted to measure the oil pressure of an aircraft engine. This pressure is measured as the difference between the oil pump pressure and atmospheric pressure. If a single-tube gage is used in a pressurized aircraft, the reading will always be low because the pressure in a pressurized aircraft is normally higher than the atmospheric pressure outside. The higher pressure will enter the gage through the vent hole and surround the bourdon tube. The gage will measure the difference between cockpit and oil pump pressure. If we install a pressure gage with a dual bourdon tube, we can vent one tube to atmospheric pressure outside the aircraft. We would connect the other tube to the oil pressure source. The gage will then read the difference between atmospheric and oil pump pressure. A dual (two) bourdon tube device is shown in figure 2-4. The moveable ends of both tubes are connected by means of two links. The intake end of one tube is connected to the source of the pressure to be measured. The intake end of the other is connected to the vent (reference) pressure.

When the pressures in the two tubes are equal, there is no motion of the free ends. The opposing forces equalize each other. A difference of pressure in the tubes will cause motion in the direction of the tube with the greater pressure. Study the mechanism shown in figure 2-5. You can see how the movement of either one of the tube ends moves the

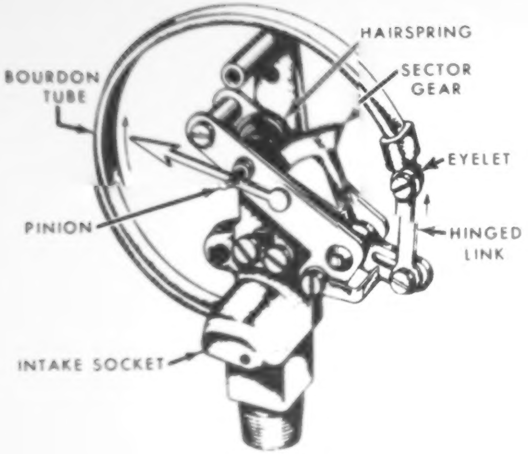

HAIRSPRING
BOURDON TUBE
SECTOR GEAR
EYELET
PINION
HINGED LINK
INTAKE SOCKET

Figure 2-1. Bourdon tube.

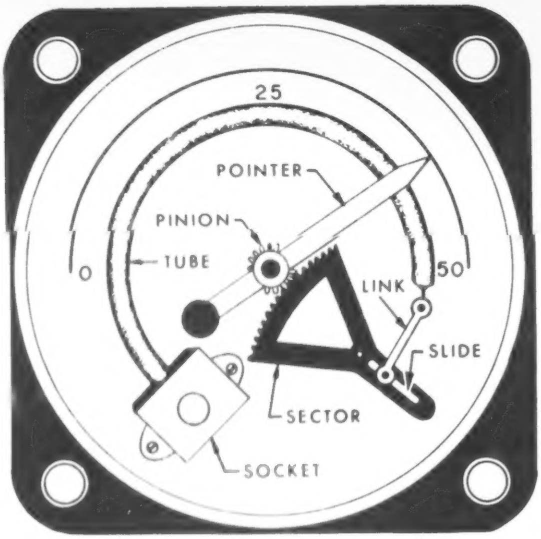

25
POINTER
PINION
TUBE
0
50
LINK
SLIDE
SECTOR
SOCKET

Figure 2-3A. Cutaway view of a bourdon tube indicator.

links. The links transmit this movement to the sector shaft and sector gear which turns the pinion gear and the attaching pointer. The hairspring maintains a pressure on the gears to eliminate backlash between the sector and pinion gears. This gives the desired pressure indication regardless of the external pressure surrounding the bourdon tubes. This type of mechanism is rugged and shock-resistant. These characteristics make it suitable for use in systems that operate under high pressures. For lower pressures, however, we need a device that is more sensitive.

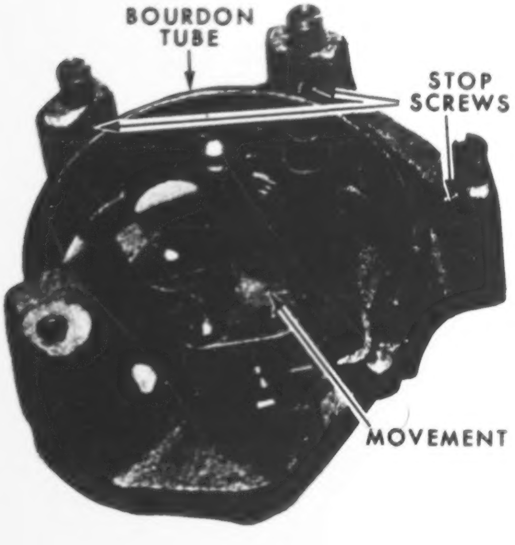
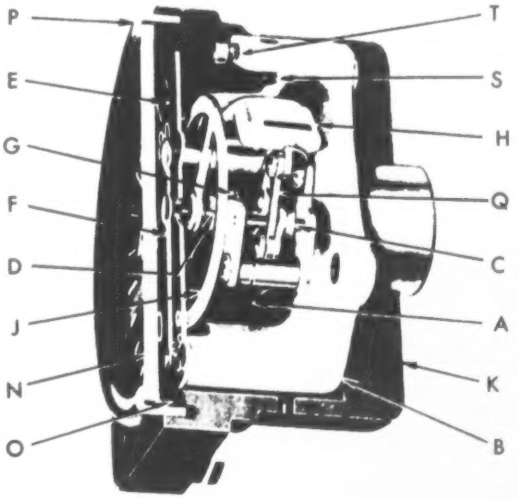

BOURDON TUBE
STOP SCREWS
MOVEMENT

Figure 2-2. Bourdon tube assembly.


P
T
E
S
G
H
F
Q
D
C
J
A
N
K
O
B

A. Bourdon Tube
B. Socket
C. Movement
D. Pinion
E. Dial
F. Pointer
G. Hairspring
H. Tip

J. Damping Disc
K. Case
N. Glass
O. Gasket
P. Lock Ring
Q. Link
S. Stop Screw
T. Lock Screw

Figure 2-3B. Front view illustration of a bourdon tube indicator.

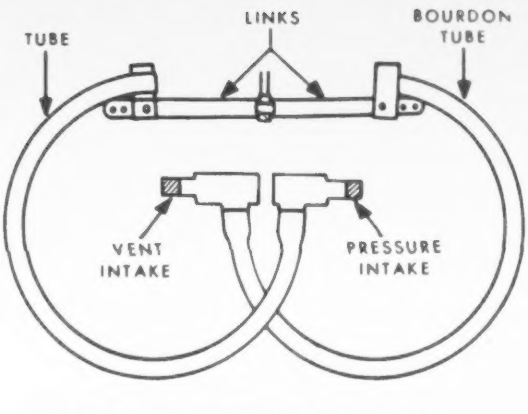


Figure 2-4. Dual bourdon tube arrangement.

Exercises (607):

1. What is the basic pressure-sensing mechanism for high-pressure indicating instruments.

2. What is the purpose of the hairspring on the dual bourdon tube device?

3. How does the direct pressuregage translate an applied pressure into a visual indication?

4. How would how the operation of a bourdon tube be affected if it developed a leak?

5. What type of pressure does the bourdon tube measure?

608. Cite the type of pressure measured by a diaphragm and specify the operational characteristics of the diaphragm.

Diaphragm. The diaphragm can measure small differential pressure changes. It is made of a phosphor bronze or a beryllium copper alloy. It is called a pressure-sensitive capsule, and moves under very slight changes of pressure.

Figure 2-6 shows a diaphragm mechanism. Notice that the pressure to be measured is applied to the inside of the diaphragm. The outside of the diaphragm is vented to atmospheric pressure through the case vent. The diaphragm responds to the difference between the source and vent pressures. If the source pressure increases, the diaphragm expands. The rocker arm picks up this motion by means of its diaphragm lever arm. It, in turn, transmits the motion through the rocker arm lever to the sector gear and, finally, to the handstaff pinion gear. This gear drives the pointer across a graduated dial.

Now compare the cutaway view of a diaphragm in figure 2-7 to the cross-section of the diaphragm in figure 2-6: pressure inlet (A), diaphragm (B), diaphragm bridge (C), rocker shaft (D), sector gear (E), pinion gear (F), dial face (G), and the case vent (H).

Exercises (608):

1. Refer to figure 2-6. Cite the type pressure measured by the diaphragm.

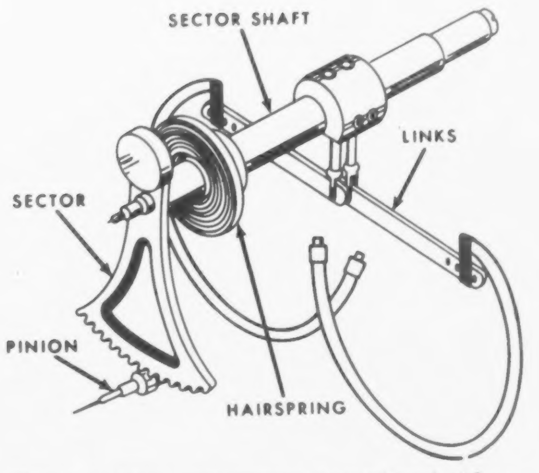


Figure 2-5. Linkage arrangement used with dual bourdon tubes.

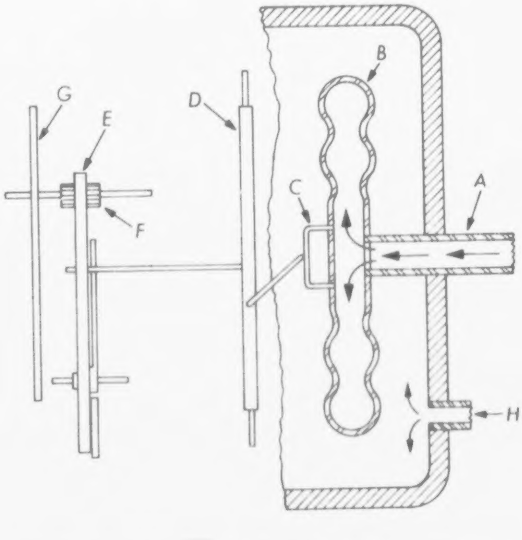


Figure 2-6. Cross-section drawing of a diaphragm mechanism.

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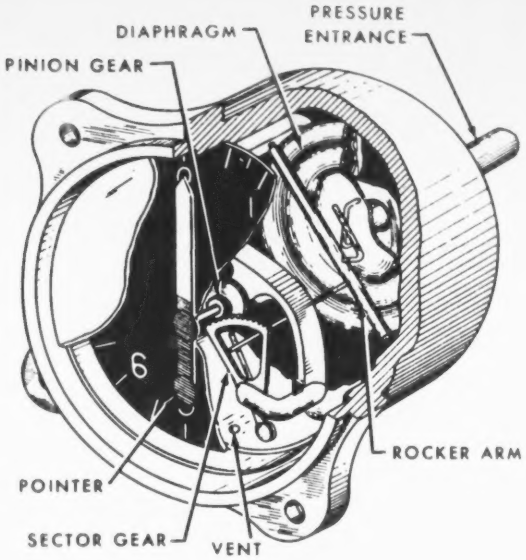

Figure 2–7. Cutaway view of a diaphragm indicator.

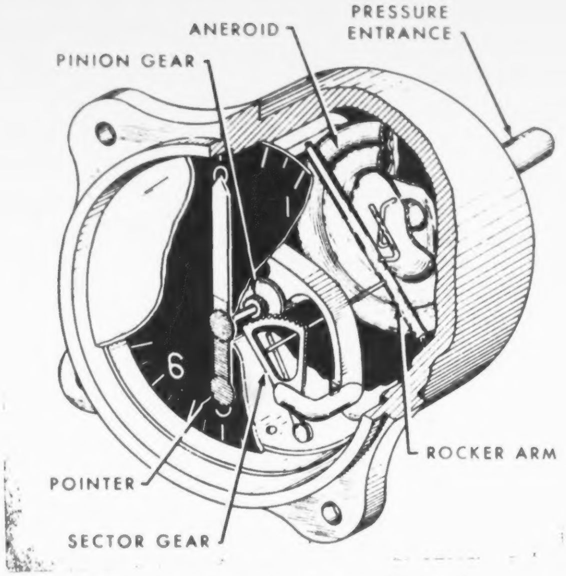

Figure 2–8. Cutaway view of an aneroid mechanism.

2. Refer to figure 2-7. What kinds of pressure are applied to the two sides of the diaphragm?

3. How does the diaphragm-equipped direct reading pressure gage transmit the expanding motion of the diaphragm to the sector gear?

609. State the type of pressure measured by the aneroid and the difference between the construction of the aneroid and diaphragm.

Aneroid. Another pressure-sensing device is the aneroid. It is used to measure absolute pressure. Figure 2-8 shows a cutaway view of an aneroid mechanism. An aneroid consists of two thin corrugated metal discs that are soldered together. This forms an airtight chamber. Before the aneroid is sealed, it is evacuated to as near a vacuum as possible. It differs from a diaphragm in that the aneroid is sealed, whereas the diaphragm has an opening to receive pressure. The pressure to be measured is applied to the interior of the airtight case, as figure 2-9 shows. The mechanism used with an aneroid is similar to that used with a diaphragm. An increase in case pressure compresses the aneroid. The movement rotates the rocker arm, which rotates the sector gear and, in turn, the pinion gear and shaft to which the pointer is attached.

We can see the cross section of an aneroid device in figure 2-9. Locate the following: the pressure inlet (A), the aneroid (B), the aneroid bridge (C), the rocker shaft (D), the sector gear (E), the pinion gear (F), and the dial face (G). If we compare figures 2-6 and 2-9 and figures 2-8 and 2-7, we find that the aneroid and the diaphragm mechanisms are similar.

Exercises (609):

1. State the type pressure measured by the aneroid.

2. State the major difference in construction between a diaphragm and an aneroid-sensing mechanism.

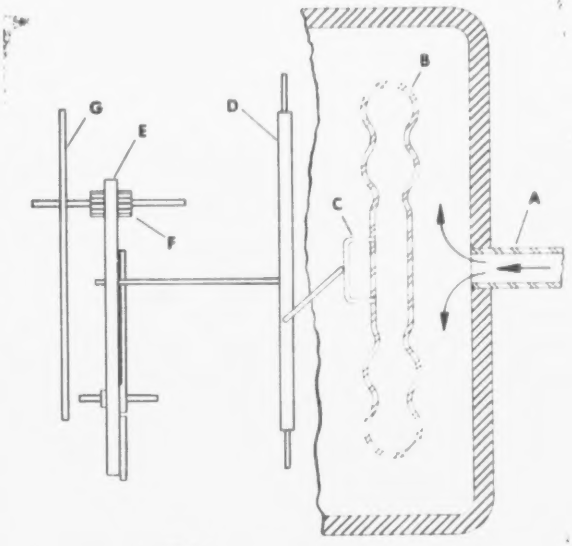

Figure 2–9. Cross-section drawing of an aneroid mechanism.

610. Specify the uses of bellows-type sensing mechanisms.

Bellows. In some systems, low pressure can be sensed and measured by a bellows device (fig. 2-10) rather than by a diaphragm or aneroid. The bellows can be used to measure either absolute or differential pressure. This depends on how it is constructed. The bellows is more rugged than either the diaphragm or aneroid. It is, therefore, less apt to be damaged from the stress and strain of rapid pressure changes. The bellows device is commonly found in manifold pressure gages, fuel pressure gages, in some remote indicating systems.

The dual bellows is the most common type of bellows device used. A simplified drawing of a dual bellows is shown in figure 2-11. Study the figure closely. You will notice that two flexible, thin-walled metal bellows are arranged so that they oppose each other. The outward end of each bellows is firmly anchored. The inner ends are connected by the linkage that actuates the pointer. When the applied pressure increases, the pressure bellows expands. This moves the linkage. When the linkage moves, it will position the pointer. At the same time, it compresses the sealed bellows. As the sealed bellows is compressed, its internal pressure increases until it is equal to the pressure in the pressure bellows. At this time, the pressure bellows will come to rest, and the pointer will indicate the applied pressure. Of course, the crude linkage shown in figure 2-11 would not be used, because it will not give enough pointer movement. Instead, you will find a pointer-moving device like the one in figure 2-12. It converts a small linear movement into a large radial movement of the pointer.

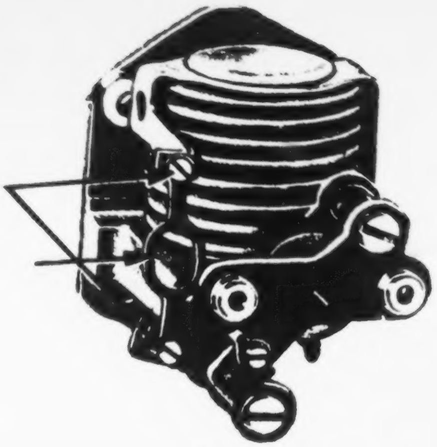

Figure 2-10. A typical bellows assembly.

When one of the bellows is connected to a source to be measured and the other is sealed, the instrument is designed to measure absolute pressure. When both bellows are connected to two sources of pressure, the instrument measures differential pressure. You can look at the way a bellows is connected and determine if the instrument measures absolute or differential pressure. Note the similarity of linkage mechanisms for the bellows-type pressure sensor to the mechanisms used with the other sensors you have studied.

This completes our discussion and review of pressure-sensing devices. It is important for you to remember that direct-reading pressure gages come in many sizes and shapes. They may be designed to indicate either high or low pressures. The range and type of pressure will determine the type of sensing element used in the pressure gage.

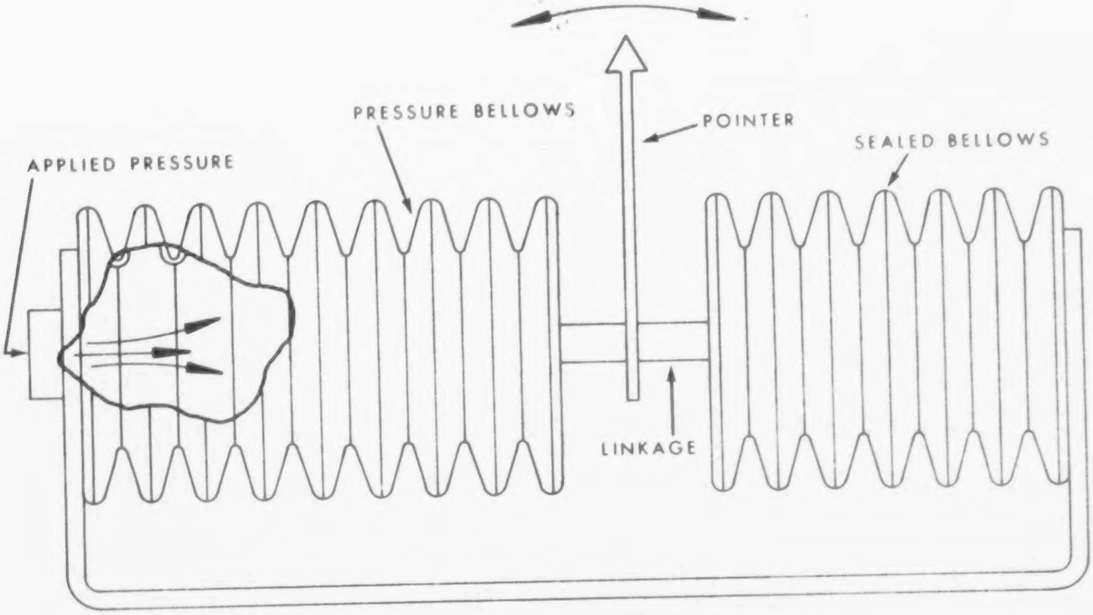

Figure 2-11. Simplified illustration of a dual bellows arrangement.

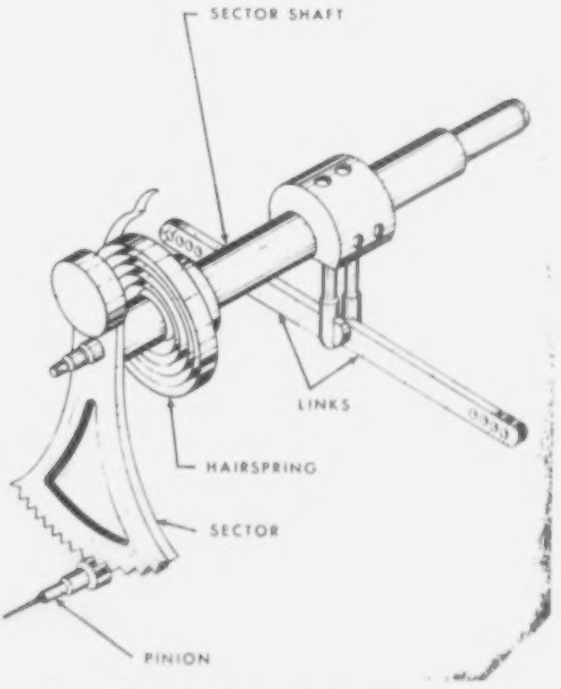

Figure 2-12. Dual linkage arrangement.

Exercises (610):

1. What type(s) of pressure can be measured by bellows?

2. What advantage does the bellows provide over the diaphragm or aneroid?

3. What bellows setup is used to measure absolute pressure?

4. What determines which sensing device is used for a specific application?

2-2. Application and Maintenance of Direct Reading Pressure Gages in Specific Systems

We have covered pressure-sensing devices which are types of metal containers that will expand, contract, or straighten out when pressure is applied to them. We had to study the direct pressure gages themselves to cover their elements. In this section, we will study direct pressure gages in detail—their construction, use, and operation. During the early days of aviation, direct pressure gages were used to measure all types of pressure, including oil pressure, water pressure, fuel pressure, and air pressure.

611. Specify uses of direct pressure gages.

Uses of Direct Reading Pressure Gages. Modern aircraft are equipped with hydraulic systems that are pressurized by pumps driven by the engine(s) or separate electric motors. These systems furnish pressure to operate such systems as the retractable landing gear, nose wheel steering, crosswind crab, brakes, and flight controls, such as ailerons, flaps, rudder, and elevators. A typical hydraulic system has a reservoir for the supply of hydraulic fluid and one or more pumps to circulate the fluid and pressurize the system to a useable pressure, usually 3,000 psi. In most hydraulic systems, it is necessary to pressurize the fluid reservoir (accumulator). This is especially true in highflying aircraft. Pressurizing the accumulator does two things: first it stops the fluid from foaming at high altitudes; second, it insures a positive supply of fluid to the pumps.

Because the hydraulic systems are necessary for the control of modern aircraft in so many ways, the pilot must know if these systems are functioning properly. For this reason, most hydraulic pressure systems have a direct pressure gage mounted on the accumulator to monitor the pressure in it. Many also have direct pressure gages in the cockpit so that the pilot can monitor available pump output hydraulic pressure. Most use an electrical system with a remote sensor, though. We will discuss these later. A warning light that is operated by a pressure switch is also used to warn the pilot when the available pump output pressure drops below a certain level.

Hydraulic actuators are used to convert the fluid pressure into mechanical force or motion, either linear (in a straight line) or rotary, depending upon the using system. Valves control the direction of fluid flow, thereby controlling the direction of actuator movement.

The direct pressure gages on the accumulators and in the cockpit are very similar. They both use a bourdon tube and the typical mechanical movement you just studied. A vent in the bottom of the case keeps the internal pressure (inside the case around the tube) at atmospheric pressure. It also serves as a drain for accumulations of moisture.

These gages are used in many different hydraulic pressure systems; therefore, each type of gage is calibrated for installation in a specific type of hydraulic system. When the hydraulic pumps are not operating, the accumulator gage shows, in psi, the preload air pressure in the accumulator. When the hydraulic pumps are operating, the accumulator gage shows the total system pressure. Because of where it is connected into the hydraulic pressure system, the gage in the cockpit shows total system pressure. Both are marked psi × 1,000. This means the 1 represents 1,000 psi, the 2 represents 2,000 psi, and midway between the 1 and 2 indicates 1,500 psi. Direct pressure gages are also used to measure cabin differential pressure, cabin altitude, bleed air for the air conditioning, vacuum systems, etc. These are very low-pressure systems; therefore, the sensing elements will be diaphragms, bellows, or aneroids.

Inspection. The inspection requirements of the direct reading pressure gage consist of checking the following: condition of the cover glass, condition and proper placement of the range and slippage marks, security of mounting, and general overall condition. Look for fluid or vapors inside the cover glass. They could indicate a leak in the sensing element of the pressure gage.

Removal and installation. THe general procedures for removing and installing direct reading pressure gages were covered in Chapter 1 of this volume. In addition to those general procedures, remember that fluids under high pressures can be very dangerous. Always bleed the pressure off the system before opening any hydraulic lines. You can do this by turning the pumps off and cycling the brakes, flight controls, or other systems operating that hydraulic system. Consult the applicable TO.

If you must work in an area away from the controls of the hydraulic system, pull and tag the appropriate circuit breakers and put a danger tag on the switch for the pump. If pressure can be supplied to the system by an engine driven pump, also put a danger tag on the engine controls.

Plug the pressure inlet port of the indicator you remove. If you must leave your work area before you install a new indicator, plug or cap the open lines on the aircraft. If you leave the aircraft before installing a new gage, document the removal of the old gage and the open lines on the AFTO Forms 781A. Use the red X symbol.

When you do install the new gage, use new mounting hardware and seal, and be careful not to damage the seal. As with any instrument installation, use all of the hardware the TO calls for. If it says to use four screws, then use four screws. Install range marks, if required, as shown in the applicable -1 TO. Clean your work area when you are through. Then perform an operational check to insure that your repairs corrected all malfunctions and that the system is safe to use. Finally, document your maintenance actions on the AFTO Form 781A in the applicable corrective action block and complete your AFTO Form 349. Make sure you have all of your tools and parts before you leave the aircraft to go back to the shop.

Operational check. To make an operational check of a direct reading pressure gage, operate the system in which the gage is located. If you are to check a hydraulic pressure gage, you must pressurize the system. In many cases, you can do this by turning on the electrical pumps. For other systems, the engine will have to be operated. In this case, you will have to ask for qualified engine runup people to assist you. Engines must be operated by qualified personnel only.

During an inspection or operational check, you may find a discrepancy involving a direct reading pressure gage. You will be responsible for the troubleshooting, bench check, and possible repair of the faulty gage. Your first step is to determine if the gage is at fault or if the fault is in the pressurized system. You do this by troubleshooting.

Troubleshooting. Most direct reading gage problems fall into two categories: (1) fluctuating (oscillating) pointers, or (2) high or low readings. However, these gages have a good longevity record and seldom cause trouble.

The simplest way to begin troubleshooting is to substitute a known good pressure gage for a suspected bad one. If the trouble still exists, it stands to reason that the fault is in the system and not in the gage. If the substitute gage reads normal, then the trouble has been isolated to the suspected gage.

An oscillating pointer of a pressure gage that measures liquid pressure is usually caused by air trapped in the line going to the gage. This oscillation can be corrected, in most cases, by removing the air. To bleed the system, first place an open container under the pressure connection at the rear of the gage is to catch any liquid during bleeding. With pressure on the system, slowly loosen the connection at the rear of the gage until a small amount of liquid comes out. As the trapped air comes out of the line, you will see a bubbling effect. Allow the connection to remain loose until the bubbling stops and the liquid flows steadily. Retighten the connection and perform an operational check of the system. Some direct reading gages have a bleeder connection on the rear of the indicator. In this case it is not necessary to loosen the pressure connection. Bleeding should only be done on low-pressure systems such as fuel and oil pressure systems. Three thousand psi of hydraulic pressure is very dangerous. Under that much force, hydraulic fluid could penetrate deep into your body. If you are unable to correct a defect in the pressure gage, then it must be removed and taken to the instrument shop. Here it will be bench checked and repaired. Before we discuss the bench check procedures, take a look at the test equipment used for this operation.

Exercises (611):

1. What are the inspection requirements for the direct reading pressure gage?

2. What is the simplest method for troubleshooting a direct reading pressure gage system?

3. Specify the maintenance operation that will usually remedy an oscillating pointer on a direct reading pressure gage which measures liquid pressure?

612. Specify the purpose and proper use of the deadweight tester.

Deadweight Tester. A very common piece of test equipment is the deadweight tester. This tester is used to test pressure gages and other pressure equipment.

The twin-seal hydrostatic pump test unit is the basic component for all tests. It is a hand-operated, piston-type pump. It was especially designed for testing instruments such as pressure gages. Several models of this type of tester are in use today. One model uses a set of master gages for checking other pressure units; it is classed as a portable test unit. There are four test gages, each 4½ inches in diameter. Each gage has a specific range; one from 0 to 160 psi, one from 0 to 600 psi, one from 0 to 5,000 psi, and the last from 0 to 10,000 psi.

Another type is the one with a complete set of weights. Each set of weights comes complete in a carrying case that is also used for storage and protection. The weights must be checked once a year against standards to insure their continued accuracy. The tester itself should be stored when not in use. This prevents damage and loss of parts. With proper care, this tester will last for many years and require only minor maintenance.

The deadweight attachment consists of a cylinder (for mounting on the test pump), one low-pressure piston installed, and one high-pressure piston. The weights produce pressure varying from 5 to 2,000 psi when used with the low-pressure piston, and from 25 to 10,000 psi when used with the high pressure piston.

The preparation of this tester for use is simple. Merely check the supply of liquid in the hand pump reservoir by removing the filler plug, which is located on the end of the pump and reservoir unit. Inspect and fill the reservoir after closing the vent located on the top center of the unit. Any medium grade oil may be used to service the tester. Most instruments use either instrument oil or hydraulic fluid for this purpose. There is one exception to the use of oil, however. That is when the pump is to be used to check oxygen gages. The pump must then be cleaned and filled with glycerin.

Basically this tester unit functions much like any other hand-operated pump. During operation, the hand lever operates a piston-type pump. This forces oil from the reservoir to the outlets. Whenever the relief valve is closed, pressure is developed in the system. When the valve is open, it releases the oil pressure to the reservoir.

It is hard to get the exact pressure desired with this pump. To get a fine pressure adjustment, another piston is installed on the pressure side of the pump. The fine adjustment on the piston is a star-shaped valve which has an X-shaped handle. Turning this valve in depresses the piston, thereby applying more pressure to the oil, but in small increments. Turning the handle out lowers the pressure.

To arrange for deadweight testing, install either the low- or high-pressure piston in the deadweight attachment. This will depend upon the range of the gage to be tested. Attach the gage to the pump. Rotate the weights slowly by hand, while building up pressure with the hand pump, until the weights are raised about one-half inch. Raising the weights any more than one-half will not change the pressure output of the pump. It does, however, increase the chance that the weights will become dislodged, allowing the oil to escape from the pump. The total value of the weights lifted equals the total deadweight pressure in psi. Be sure that you use the correct numbers that appear on the weights. Remember, the weights are stamped with two numbers. These indicate the pressure that the weight will produce. The 4-inch diameter weights are stamped with a No. 20 in one place and a No. 100 in another place on the top surface. When used with the low-pressure piston, the weight produces 20 psi. The same weight produces 100 psi when used with the high-pressure piston. The low-pressure piston is stamped 5 and produces 5 psi by its own weight alone. The high-pressure piston is stamped 25 and produces 25 psi.

Use caution when working with the deadweight cylinder, piston, and platform assemblies. They are accurately machined and highly finished fittings. Treat them carefully to prevent scratching or galling them. The cylinder and piston can be cleaned and oiled with any type of medium weight oil.

Always rotate the piston and platform assemblies when inserting or removing them from the cylinder. Such rotation relieves the friction of a close fit, and the piston will slide in and out freely. Never push or pull the pistons straight in or out without first turning or rotating the parts. The surface finish may be damaged, and leakage may result. Always release pump pressure before removing any weights.

Use extreme caution when operating the pump—to prevent excessive pressure from entering the gage under test. The air vent should be open during operation. Close it only when filling the reservoir and during periods of storage.

Exercises (612):

1. What is the purpose of the deadweight tester?

2. What is the total pressure range of the tester using deadweights.

3. What precaution must you take when testing oxygen components on a deadweight tester?

4. How the deadweight tester adjusted for a precise pressure?

5. What precaution must you observe when testing a direct reading pressure gage with the deadweight tester?

613. Specify bench checking procedures of direct pressure gages.

Bench Testing. The repairman must make certain checks or tests to determine if a pressure gage is accurate within specified limits. If the instrument is out of tolerance, he or she makes minor adjustments to correct it. These adjustments are calibrations. We will discuss some common types of errors found in pressure instruments, the testing for these errors, and the adjustment of the instrument to make it read correctly. The repairs that can be made are governed by your particular organization.

Scale error. One of the tests made to determine the accuracy of the instrument is called the scale error test. This test is a comparison of readings between the instrument being checked and a master test standard. The difference between the readings of the instrument being tested and the master is called scale error. If the instrument reads high, it is said to be fast. If the reading is lower than the master, the instrument is said to read slow. In some instances, it is impossible to adjust an instrument so that it will be perfectly accurate at all points on the dial. A small amount of error may be permitted and is considered a tolerance. Scale error tests are performed whenever the instrument is thought to read incorrectly. It is also performed after long periods of storage. During calibration, scale error tests are made to determine the amount and type of error present, and also to check the effect of each adjustment as it is made. A final scale error check is made after calibration. The results of this final test are usually recorded on a calibration card. When making the scale error test, be sure you tap the instrument or subject it to a slight vibration before each reading is recorded.

During scale error test, several types of curve and range errors may be discovered. Some of these errors may be remedied by calibration. Others may require repair or replacement of parts.

Curve error. If pointer indications at both ends of the dial are correct but errors occur in the middle range, the instrument has curve error. Usually the amount of error varies at different points on the dial. The error is called curve error because the readings form a curved line when plotted on a graph. If the instrument is accurate, the readings appear as a straight line. It is also possible to have curve error along with range error. With range error, the pointer travel can be either too much or too little.

Range error. The range of an instrument is the total amount of pressure that the instrument is designed to measure. If an instrument is designed to measure from 0 to 200 psi, the range is from 0 to 200 psi. If we apply 200 psi to this instrument, the pointer should travel all the way from 0 to 200. If the pointer fails to travel to the 200 mark or if it moves beyond the mark, the instrument has range error. Range error is either too much or too little pointer travel. The readings will become progressively faster when the pointer travel is too little.

Exercises (613):

1. What the bench check is made to determine the accuracy of a direct reading pressure gage?

2. What type of error is present in a direct reading gage when the pointer indications are accurate at zero and full scale, but inaccurate at midrange.

3. What type of error is present in a direct reading pressure gage when the pointer is accurate at zero, but high at full scale.

614. Specify the adjustments and steps to take when adjusting the errors in direct reading pressure gages.

Adjustment of Direct Pressure Gages. Both range error and curve error can be corrected by adjustment. In the discussion of sensitive mechanisms, we found that they contained sensitive elements, some form of mechanical linkage, and a case or housing. To calibrate such devices, you must adjust the linkage arrangement. Because of the similarity of pressure indicators, the same principle applies to all of them. For discussion purposes, however, we will consider the bourdon tube device. Figure 2-13 shows a simplified diagram of the various types of linkages.

Let's take up the correction of range error. On the bourdon tube device, you will notice that the sector tail is slotted lengthwise. This is so that the position of the linkage can be altered. By changing the distance between the sector pivot and the point at which the link is connected, you can change the amount of pointer travel. This repositioning procedure is known as changing the radius of rotation. As you can see in figure 2-13, the connection of the linkage at a point close to the pivot will produce a large amount of pointer travel for a given amount of pressure change. If the link is fastened to the sector at a point farther away from the pivot, the same amount of pressure change will produce less pointer travel.

All pressure instruments have some means for changing the radius of rotation. In each case, the adjustment is one of trial and error until you find a position that will produce the desired amount of pointer travel.

Intermediate or curve error is the result of changing straight-line motion into rotary motion. A detailed study of this action is shown in figure 2-13. This should help you to understand the relationship between the two motions. Once you understand this, you are well on your way to knowing how to correct for curve error. The circle represents the movement of a sector around a pivot. When pressure is applied, the bourdon tube moves in a straight line. This is also true of other types of sensitive elements. Furthermore, the sensitive element always moves the same distance for any given amount of pressure.

If the link could move in a straight line, it would move the same distance as the sensitive element. This is shown by the distance or space between the numbers in the straight base line in figure 2-13. Since the link is connected to the sector tail, instead of moving the distance on a straight line, it moves the distance shown on the circle.

If the total movement of the sector took place between 1 and 4, the distances that the link moved would vary. This results in curve error. On the other hand, if the movement occurred between 3 and 7, the rotary distance traveled by the sector would be nearly equal to straight-line distance. In such a case, there would be no curve error. Successful calibration of curve error means getting the sector to move in a part of the circle where rotary motion is almost equal to the straight-line motion. You do by adjusting the starting angle.

To see what is meant by starting angle, refer to figure 2-14. An angle is formed between a line drawn through the sector pivot and the link connection of the sector tail. The

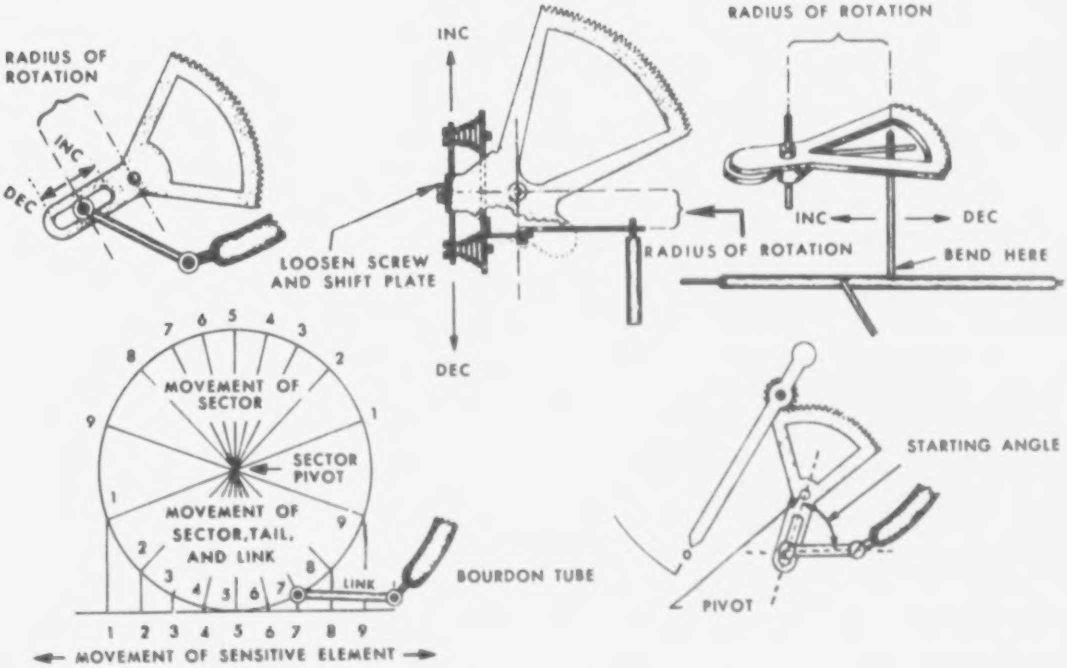
RADIUS OF ROTATION
INC
DEC
INC
RADIUS OF ROTATION
LOOSEN SCREW AND SHIFT PLATE
INC
DEC
RADIUS OF ROTATION
BEND HERE
DEC
7 6 5 4 3
8
2
9
1
MOVEMENT OF SECTOR
SECTOR PIVOT
MOVEMENT OF SECTOR,TAIL, AND LINK
1
2
3
4 5 6 7
8
9
LINK
BOURDON TUBE
STARTING ANGLE
PIVOT
1 2 3 4 5 6 7 8 9
MOVEMENT OF SENSITIVE ELEMENT

Figure 2-13. Changing the range of pointer travel.

starting angle will be correct when a line drawn through the sector pivot and the line connection form a right angle with the pointer at midscale (see fig. 2-14). When this is done, the movement will be equally divided on both sides of the right-angle position. Curve error will be minimized. When the starting angle produces a fast error, the pointer reaches the midpoint on the dial before the sector has formed a right angle with the link. A slow error is apparent when the right angle is formed before the pointer reaches midscale. By increasing the length of the link (by bending the tail of the bourdon tube), you can correct the starting angle that causes slow error. Figure 2-13 shows a few of the methods used for changing the starting angle on different types of instruments.

The first step in the calibration procedure is to set the pointer at zero. You will notice that each time you make an adjustment, the pointer will move away from zero. Each time, you must lift the pointer off and reset it on zero before making a test to check the effect of the adjustment. When calibrating, it is usually best to correct the range error first. After this has been done, check to see whether or not any errors still exist at intermediate points on the dial. If curve error is present, make the adjustment to correct the error. Then recheck the range error. Range and curve adjustments sometimes affect each other. It may be necessary to recalibrate the range. By alternately adjusting for range error and curve error, you will eventually bring the readings within tolerance.

Usually you need not repair or replace parts to correct for range and curve errors. There are some errors, however, that cannot be corrected unless you make repairs or replacements.

Exercises (614):

1. What adjustment is made to a pressuregage to correct for range error.

2. What adjustment is made to a pressure gage to correct for curve error?

3. What is the first step in calibrating a pressure gage?

4. You complete a curve error adjustment, but you find that this affects the range adjustment you just completed. What would you do to correct this condition?

615. State the errors in a pressure gage that require repair for their correction.

Errors Requiring Repair. Here we will discuss two types of of errors that require repair or replacement of parts: friction error and position error.

Friction error. Friction error is the result of binding of the parts of the indicator. Dirt, roughness, and various

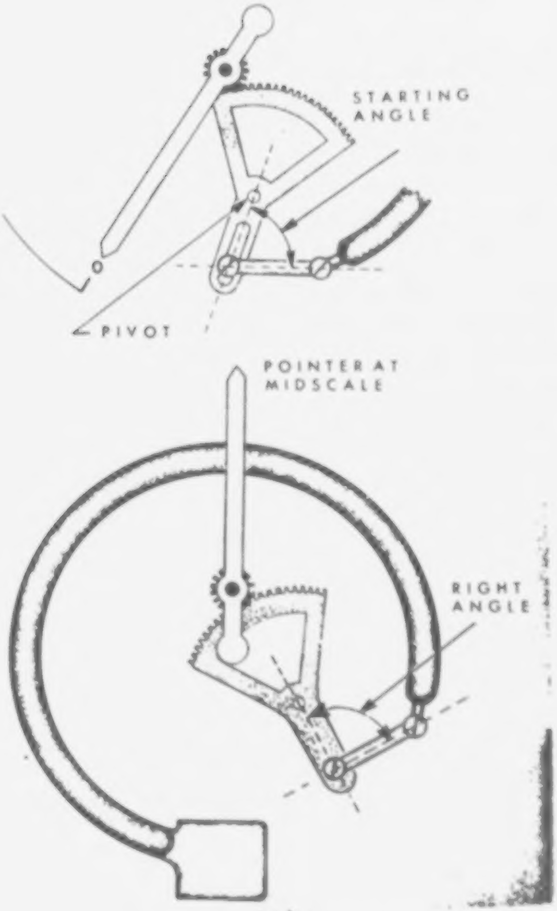

Figure 2-14. Correction for curve error.

mechanical faults may cause an instrument to bind. A friction error test is made along with the scale error test at certain points on the dial. At these points, readings are taken before and after tapping the instrument lightly. Any difference between the two readings is noted. This difference is the amount of friction error at this point. Friction can result when bearing surfaces are rough, dirty, corroded, or too tight; when sector or pinion teeth are dirty, corroded, worn, burned, or bent; when there are cracked jewels; or when the hairspring tension is improperly adjusted.

Position error. An instrument having position error will give one reading when the aircraft is flying level, another when it is banked, and still another when it climbs or dives. To test for position error, take readings when the instrument is in the natural position that it occupies in the aircraft. Then tilt it 90° forward, backward, to the right, and to the left. In each position, tap or vibrate the instrument before taking a reading. The amount of pointer change when the pointer is moved into a new position is the amount of position error. The most common causes of position error are excessive unbalance of any of the moving parts; excessive end play in the shaft and pivots; worn gear teeth, lever arms, or other contacting parts; and too little hairspring tension. Neither friction error nor position error can be removed by just making adjustments. The only remedy is to locate the cause and make the necessary repairs. Then recalibrate the instrument for accuracy.

Exercises (615):

1. What error would be present in a pressure gage if the moving parts were dirty?

2. What type of error is being checked when a reading of the pointer is taken each time the gage is tilted 90° forward, backward, right, and left.

3. What type of error would more than likely be the result of long usage of the pressure gage?

CHAPTER 3

Synchros and Variable Reluctance Systems

YOU HAVE learned that direct reading pressure gages require tubing between the point where the pressure is measured and the point where the indicator is mounted in the cockpit. Because modern aircraft have become larger, the requirements for more monitoring systems have also become greater. The transmission of various liquid pressures through a system of tubing would increase the weight of the aircraft. It also means that flammable liquids are present in the cockpit, an undesirable condition for safety reasons. These factors brought about the design of the synchronous instrument systems. The elimination of tubing not only helps to reduce weight, but it also eliminates the flammable liquids from the cockpit area.

Such systems give the pilot a constant report of the events happening at various points throughout the aircraft. Signals are electrically transmitted from these points to instruments in the cockpit. The signals are transmitted over wires that run from a transmitting device located at the point where the pressure is measured to the indicating unit.

There are several types of remote indicating systems that are categorized as self-synchronous. Such systems are often known by trade names such as autosyn, selsyn, learsyn, and magnesyn. You will have to maintain these systems. In this chapter we discuss one of each of the more common remote pressure indicating systems. You must learn the inspection and operational check procedures for these systems as well as the maintenance that you will be required to perform on them.

3-1. Synchro Pressure Systems

Autosyn is the trade name of a synchro unit made by one of the major instrument corporations. You will find the same design principles used in the learsyn and synchro units manufactured by other instrument corporations. These units depend on alternating current as an external power requirement Normally they use 26-volt, 400-Hz, single-phase, AC power. However, some synchro systems require 115-volt AC power.

A remote indicating system must consist of at least two basic components, as illustrated in figure 3-1. Other components may be added, as you will see later in this chapter. One of the basic components, a transmitter, is located near the point where the pressure is measured. This component actually measures and transmits the signal of that measurement to a second component (the indicator) in the cockpit. The indicator receives a signal from the transmitter and converts it to a numerical value. This value then can be read directly from the indicator dial. Now we have an idea of the components that make up a synchro system. As we discuss the common synchro pressure system, keep in mind that it is typical of all synchro systems. Instead of discussing them individually, we will discuss only this one.

616. Identify the functions of given components and sections of the synchro system.

Transmitter. This component has two sections: a mechanical-sensing section and an electrical transmitting section. The mechanical-sensing section may contain a diaphragm, a bellows, or a bourdon tube sensing device. The type of sensing device will depend upon the type and range of the pressure to be measured. In the typical pressure system, we will discuss how a bourdon tube is used. The mechanical section is nearly the same as the one in the direct-reading pressure gage you studied in Chapter 2. In the pressure gage, the pressure is applied to the sensing element, be it a bourdon tube, bellows, or diaphragm. The reaction (movement) of the sensing element is transferred to a sector gear by a mechanical linkage. Up to this point, the operation of the mechanical section of a synchro transmitter is the same. In the direct pressure gage, the sector gear turns a pointer shaft, but in a synchro transmitter it turns a rotor in a synchro unit. A hairspring is attached to the rotor shaft to maintain a pressure on the gears to eliminate backlash and erroneous indications due to clearance between the gear teeth. This small rotation changes the rotor alignment in relation to stators to develop an electrical signal.

The electrical section of the synchro transmitter contains the synchro unit and the electrical connector. The synchro (autosyn) is much like a small motor or generator. The major parts of the synchro unit are the rotor and stator. The rotor consists of two small coils of wire wound around a common core. The core is part of the shaft.

The rotor receives power through two slip rings on the shaft. This arrangement puts very little drag on the rotor, which is installed in ball bearings. The bearings are pressed into the ends of the synchro housing. The rotor is mounted in such a way that it is free to rotate through 360° within the stator coils. The stators are press-fitted into the synchro housing.

Indicator. The indicator is the second major component of the system. It is located in the cockpit and connected to the transmitter by electrical wiring. It consists of a synchro that is nearly identical to the synchro of the transmitter. The difference is that the rotor is free to turn. It is positioned by

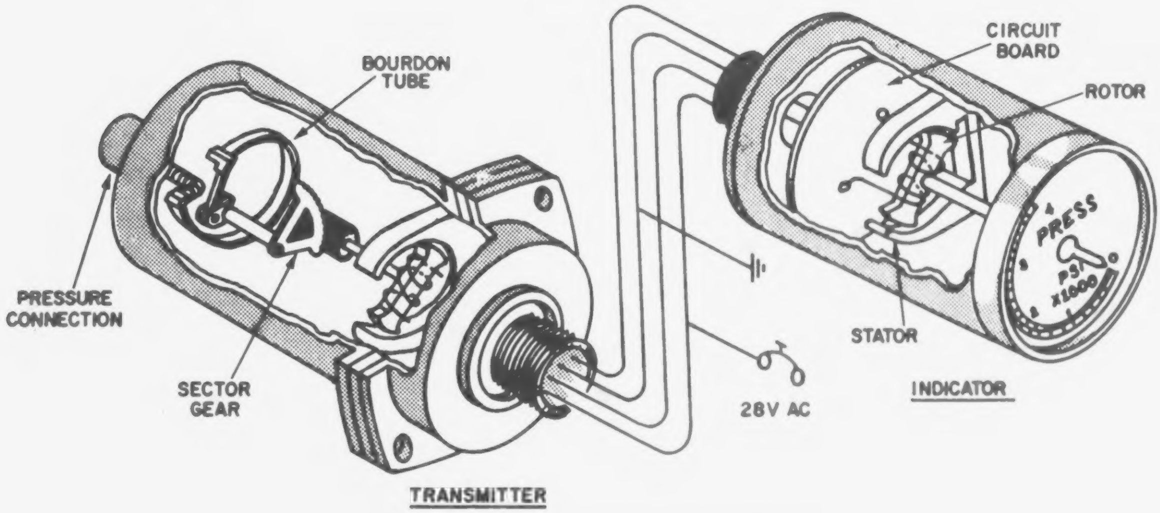

Figure 3–1. A typical synchro (remote indicating) system.

the electrical signal from the transmitter. It, too, receives power through slip rings. Also, a pointer is attached to the rotor shaft which extends to the front of a calibrated dial. This gives the pilot a visual indication of the changes that occur in the system. An electrical connector on the back of the indicator connects it to the transmitter.

Exercises (616):

1. Match synchro system components/sections listed in column A with their functions listed in column B. Write the correct letter in the space provided. Some functions are not used and some are used more than once.

Column A

Components/Sections

____ (1) Mechanical section.
____ (2) Hairspring.
____ (3) Transmitter rotor.
____ (4) Indicator rotor.
____ (5) Electrical section.
____ (6) Transmitter sector gear.
____ (7) Slipring brush arrangement.

Column B

Functions

a. Moves 320° within the stator coils.
b. Turns a pointer.
c. Conducts current to the synchro rotor.
d. Transfers pressure-produced movement to the sector gear.
e. Positioned by the sector gear.
f. Develops the signal for the indicator.
g. Maintains pressure on the gears.
h. Positions a rotor.
i. Illuminates a warning light.

617. Specify operational characteristics of the synchro system.

System Operation. Now you know the units that make up a synchro system. Next, consider just how the system operates. We will now tie the two units together to form a typical synchronous system.

The synchro transmitter is located near the point where the pressure is to be measured. A short length of tubing connects the pressure point of the system to the pressure port of the transmitter. When pressure is present in the system, it is sent through the tubing into the pressure port of the transmitter. The pressure is sensed by the mechanical-sensing mechanism. As a result of this pressure, a movement takes place in the mechanical-sensing device. This movement is transmitted through the mechanical linkage to the sector gear. As the sector gear moves, it turns the pinion gear on the end of the rotor shaft. This turns the rotor within the stator windings of the synchro unit. Now the pressure has been sensed by the mechanical section of the transmitter. The indication is sent to the indicator.

The synchro operates on the same principle as a transformer. The principle is that of induction. The amount of induction from a synchro rotor into the stator coils is determined by the angular position of the rotor in relation to the stator coils. Figure 3-2 shows the electrical hookup of a synchro unit of the transmitter. No. 2 represents the synchro unit of the indicator. The letters A through D represent the actual pin letters on the electrical connectors of the transmitter and indicator. The external system power to the system (normally 26-volt, 400-Hz, single-phase, AC power) is connected to the rotors of both synchros through pins A and B. Notice, in figure 3-2, that the stators of the two units are directly connected to each other. Assume that the synchro system is in operation. Power is applied to the synchro rotors. The pressure in the system under measurement is at zero. In this case, the sensing device in the transmitter is in a static state (no movement). With this condition, the rotors of the two synchro units are aligned parallel with stator coils A. The pointer is at zero, as shown in figure 3-2. When the rotors of both synchro units are aligned, no current will flow in the stator coils.

You may be wondering why no current is flowing in the circuit. When the rotors are aligned, identical voltage is

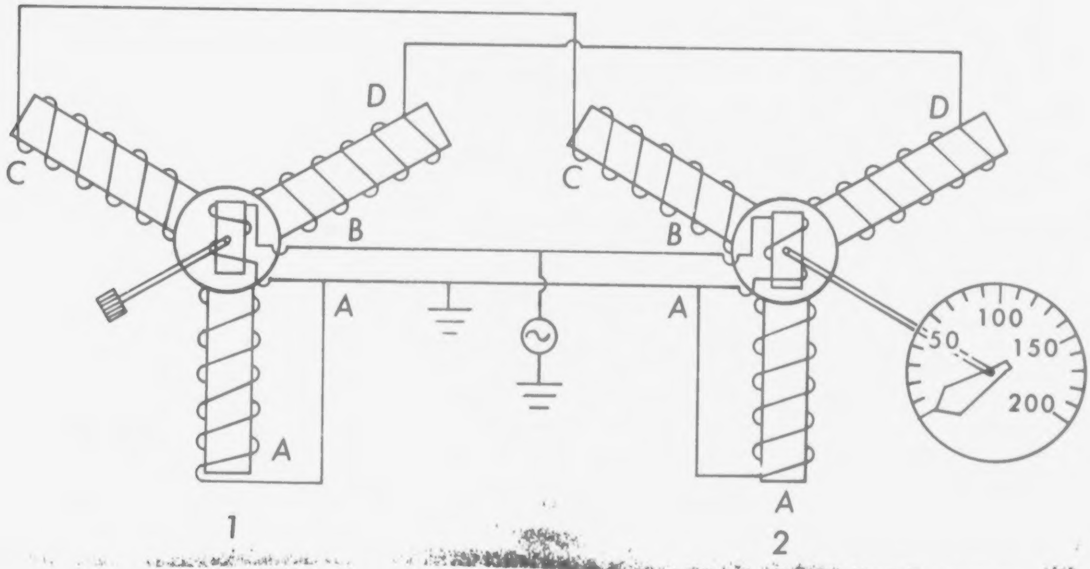

Figure 3–2. Synchro system with rotors aligned.

induced into the stator coils of the transmitter and indicator. As long as there is no difference in potential between the two stators, no current can flow. Look at figure 3-2. Notice that winding A of both the indicator and transmitter synchros have maximum induction. The reason for this is that winding A of each synchro stator is exactly parallel with the rotor. During any given instant, the voltage induced into winding A of the transmitter and indicator synchros will be exactly the same. No difference in potential will exist between the two stators.

The same is true of windings C and D, except that maximum induction will not take place because the windings are not parallel to the rotor.

Synchronization of the rotors in the system is almost instantaneous. Let's go through each step of this event for clarity. Look at figure 3-3. You will see that the rotor of the transmitter synchro is no longer parallel to winding A of the stator. This was caused by a pressure increase being felt by the mechanical-sensing device. This pressure increase has caused the transmitter rotor to be an aligned parallel to winding D of the transmitter, and a difference in potential exists between the D windings of the transmitter and indicator.

When voltage is induced into the stators, it results in a difference in potential, and current begins to flow in the circuit. The path of current for a given half-cycle of the AC

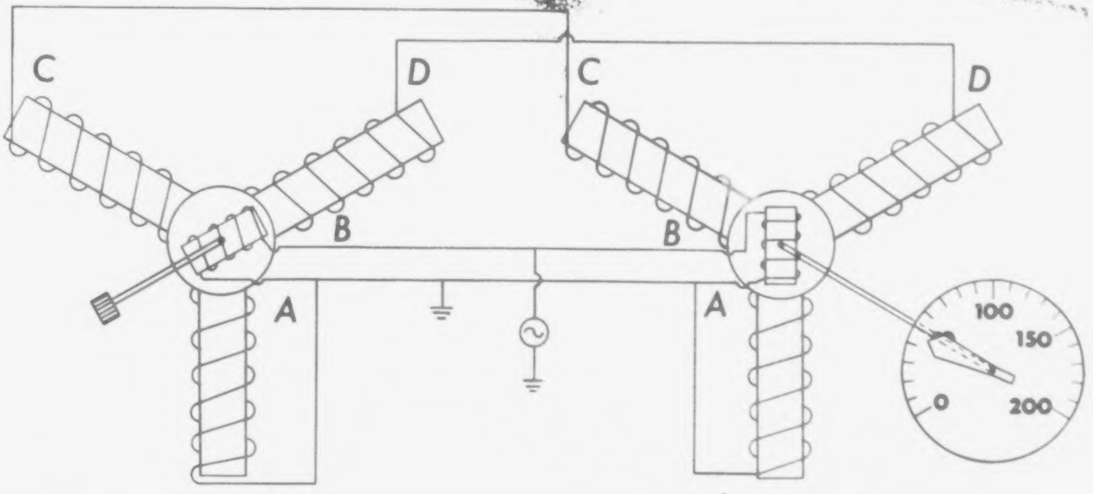

Figure 3–3. Synchro system with rotors *not* aligned.

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power is through coil A and out through windings C and D of the indicator synchro. This current flow in the indicator stator coils creates a magnetic field around them. Now we come to the point where the actual synchronization of the rotors takes place.

The rotor of the transmitter is held in a certain position. This is shown in figure 3-3. It cannot move unless the pressure applied to the mechanical-sensing device changes. It is the position of this rotor within the transmitter stator coils that has caused current to flow in the indicator stator. The fact that current is flowing in the stator coils has set up a magnetic field around the stator. You must also remember that a magnetic field has been created around the rotor of the indicator synchro. This magnetic field is created by the external AC voltage being applied to the rotor. You can see that we have two magnetic fields within the synchro unit that will try to align with each other. They will act the same as two bar magnets that are placed close enough together to influence each other's magnetic field. The rotor is the only freely rotating unit within the indicator. It is repositioned as the magnetic fields align themselves. It aligns itself parallel with stator coil D of the indicator synchro. The pointer of the indicator is connected directly to the rotor shaft. Therefore, it will be repositioned with the rotor to show the pressure increase on the indicator dial. Now the rotors are once again synchronized. Both synchro stator coils are receiving the same induced voltage. Current will cease to flow. Remember, AC voltage is applied to the rotors and the magnetic polarity is constantly changing. However, the magnetic polarity of the rotors with respect to their stators will not change.

There is no pointer pulloff device (hairspring) in the indicator. Once power to the system has been turned off, no force is available to move the pointer. For this reason, the synchro indicator pointer will remain at its last indication when power to the system is lost.

Exercises (617):

1. What is the amount of induction from the rotor to the stator of the synchro unit determined by?

2. What is the normal power requirement for a common synchro system?

3. Will current flow in a synchro system stator circuit when the rotors of both synchro units are aligned identically? Why?

4. When will the maximum induction from the rotor to the stator coil take place in a synchro unit?

5. How is the rotor of the synchro unit repositioned in a synchro transmitter?

6. What electrical condition is created around the stator coils of a synchro unit when current is flowing through the coils?

7. What actually causes the rotor of the synchro unit in a synchro indicator to align with the rotor of the synchro unit in the transmitter?

8. What will the indicator of the synchro system show when external power to the system is lost? Why?

618. Specify the synchro system inspection requirements and list the operational check procedures.

Inspection. During a visual inspection of a synchro system, you will be required to check the following items:

- Indicator.
- Transmitter.
- Wiring.

Indicator. Inspect the indicator for condition of the cover glass, condition and proper placement of range markings, security of mounting, and general overall condition.

Transmitter. Inspect the transmitter for security of mounting, condition of shock mounts, evidence of leakage, and proper safetying.

Wiring. Inspect the system connecting wiring for security of mounting, electrical connectors for proper safetying, and the entire system for overall condition.

If, while performing an inspection of a synchro system, you should remove an electrical connector or for any reason disturb the components of the system, you must perform an operational check of that system.

Operational Check. Your first step in performing any operational check is to consult the applicable aircraft TO. The TO procedures for applying electrical power to the aircraft must be followed in detail. If you do not follow these procedures, you can cause serious damage to the aircraft and to personnel who may be around it. Now apply power to the system to be checked. Operate the aircraft system in which the synchro system is used. In the case of a fuel pressure system, this normally would require turning on the fuel system booster pumps. However, in the case of an oil pressure system, the engine may have to be operated. This must be done by qualified personnel only.

If the aircraft systems cannot be operated, you can perform an operational check by using a portable test unit. The one described for direct reading pressure gages can be used. This portable pressure test unit can be connected to

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the pressure port of the synchro pressure transmitter. By using the hand pump, you can supply pressure to the system.

The method you use to supply pressure to the system will depend largely upon maintenance circumstances. During the operational check, you should check to see if the indicator pointer moves smoothly and with minimum oscillation to the required point on the dial.

Exercises (618):

1. What must you check for when inspecting a synchro system transmitter?

2. What is the first step to take when operationally checking a synchro system?

3. If an operational check requires that the engine be operated, who must operate the engine?

619. Identify the functions of tester units and sections of the test equipment used to check the synchro system components.

Test Equipment. The test set most commonly used to bench check synchro system components is the synchro instrument field tester. This test set can also be used as a field tester to aid you in troubleshooting synchro systems on the aircraft.

The test set consists of three calibrated synchros, a servoamplifier, an isolation transformer, potentiometers, and switches. All of these units are mounted in a standard portable instrument case weighing about 22 pounds. The test set requires 115 volts or 26 volts, 400-Hz, single-phase, AC power for operation. The operating controls, indicators, and cable connectors are located on the front panel. These are shown in figure 3-4. The panel is protected by a cover when the test set is not in use. A space is provided for storage of the various cables supplied with the test set.

The test set consists essentially of two test circuits: a transmitter test circuit for checking synchro indicators and an indicator test circuit for checking synchro transmitters. Locate the following items in figure 3-4: synchro indicator (A), test selector switch (B), synchro transmitter (C), sync indicator switch (D), motor voltage fixed-phase control potentiometer (E), motor voltage variable-phase control potentiometer (F), motor volts selector switch (G), servoamplifier gain control (H), test unit connector (J), power circuit fuses (K, L, and M), power-on lamp (N),

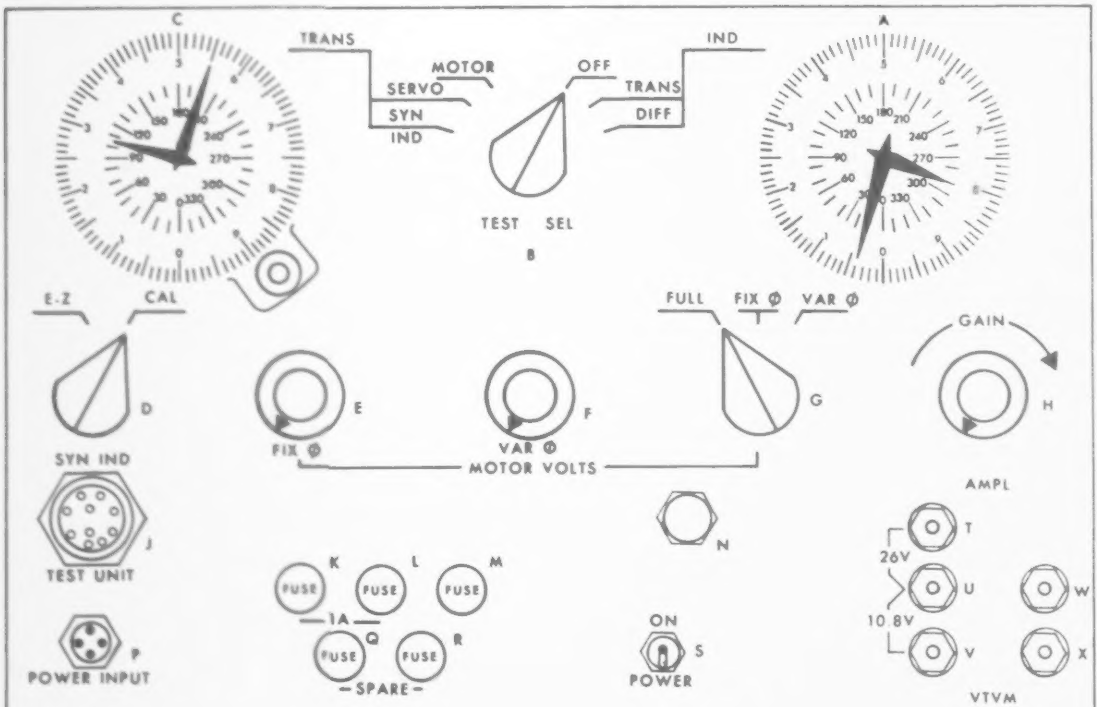

Figure 3-4. Synchro tester panel.

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power input connector (P), spare fuses (Q and R), power-on switch (S), and VTVM binding posts (T, U, V, W, and X). Now that you are familiar with the items of the test set and their locations, we can discuss the function of each of these items. Refer to figure 3-4 as we discuss these functions.

The synchro indicator (A) is calibrated in degrees of the tester range. This gives us a large scale which provides precise indications for making adjustments or measurements. It has two pointers that indicate from 0° through 360° in .1° increments. The indicator serves as the receiver synchro (indicator) when testing a synchro transmitter. The synchro indicator shown in figure 3-4 indicates approximately 290.4°. The small pointer moves 10° for every complete revolution of the large pointer.

Notice that the test selector switch (B) has a position for each of the test functions that you can perform with the tester. The switch is shown in the OFF position. When the switch is placed in the TRANS position, the synchro indicator becomes the indicator standard for checking synchro transmitters. If you place the switch in the DIFF position, the indicator can be used as a readout for testing differential synchros. If you place the switch in the MOTOR position, it provides the circuits necessary for testing the low-inertia motor of a servoed synchro indicator. If you move the switch to the SERVO position, it connects the synchro transmitter (C), through the servoamplifier, to the indicator under test. When you place the switch in the SYN/IND position, it connects the synchro transmitter to a regular synchro indicator for testing.

Notice in figure 3-4 that the synchro transmitter (C) is calibrated in the same manner as the synchro indicator. The dial of the synchro transmitter in figure 3-4 indicates approximately 105.5°. You can adjust the pointers are adjusted to the desired degree reading by turning the small knob located on the bottom right side of the transmitter.

The sync indicator switch (D) shown in figure 3-4 has two positions: E–Z and CAL. The CAL position designates the calibrate position. The switch is left in this position for all calibration tests of synchro indicators. The E–Z position of this switch designates electrical zero. Use position only when performing electrical zero checks of synchro indicators.

The section outlined as motor volts on the front panel of the tester includes the fixed-phase potentiometer (E), the motor variable-phase potentiometer (F), and the motor volts selector switch (G). Use this section of the tester when testing the low-inertia motor of a servoed synchro indicator. Use the amplifier gain control (H) to adjust the servoamplifier output when checking a servoed indicator.

The power circuit of the synchro tester includes the power input connector (P), the three fuses (K, L, M), the power-on switch (S), and the power-on lamp (N). Spare fuses are provided as shown in figure 3-4 (Q and R). The VTVM binding post on the lower right corner of the tester provides a means of connecting a VTVM to the different circuits of the tester. This is done to check and monitor the voltages while you are performing bench tests of the various components.

Before we discuss the procedures you must follow when bench checking a synchro component, let's see what is required of you to prepare the synchro test set for operation. The first step you take is to connect the test set to a proper power source. A power input cable is provided with the tester. Remember that you can use either a 115-volt or a 26-volt, 400-Hz, single-phase, AC power source. If you use a 115-volt source, connect it across pins A and C of the power input connector. If you use a 26-volt source, connect it across pins B and C. Before you connect the power to the tester, place the switches and controls in the following positions:

- Power-on switch .... OFF.
- Test selector switch .... OFF.
- Amplifier gain control .... FULL COUNTERCLOCKWISE.
- Sync indicator switch .... CAL.

Exercises (619):

1. What is the most commonly used test set for bench checking components for the servoed synchro system?

2. What are the power requirements for the synchro field test set?

3. How far will the small pointer on the synchro tester will move for one revolution of the large pointer?

4. Match the tester units/sections listed in column A with their functions listed in column B by writing the correct letter in the space provided. Some functions are not used and some are used more than once.

Column A

Tester Units/Sections

____ (1) Synchro indicator (A).
____ (2) Test selector in DIFF position.
____ (3) Test selector in MOTOR position.
____ (4) Test selector in SERVO position.
____ (5) Test selector in TRANS position.
____ (6) Test selector in SYN/IND position.
____ (7) CAL position on SYN/IND.
____ (8) E-Z on the SYN/IND.
____ (9) Motor volts section.
____ (10) Gain control.
____ (11) Synchro transmitter (C).

Column B

Functions

a. Checks regular synchro indicators using the synchro transmitter (C).
b. Adjusts servoamplifier output when checking a servoed synchro indicator.
c. Checks synchro indicator accuracy.
d. Aligns the indicator pointer on electrical zero when activated.
e. Gives indications in degrees.
f. Checks synchro indicators through a servoamplifier in the test using the synchro transmitter (C).
g. Adjusts the speed of the servoed synchro.
h. Tests differential synchros.
i. Serves as a receiver synchro.
j. Designates electrical zero position.
k. Aligns the indicator pointer on mechanical zero when actuated.
l. (Synchro indicator A.) Serves as a standard for checking synchro transmitters.

Column A *Tester Units/Sections*	*Column B* *Functions*
	m. Designates the calibration position.
	n. Checks low-inertia motor in servoed synchro indicato.

620. State the purpose of and procedure for performing an electrical zero and scale error check when bench checking the indicator.

Bench Check. The a bench check that we will use as an example is the single-synchro indicator. You should remember that the test, as we discuss it, will be the procedures used for a typical synchro indicator test. For detailed procedures, you must consult the applicable TO for the autosyn field tester you are using and for the indicator that you are testing. You will need to check the TO for a particular indicator to convert the degree reading of the tester to the actual psi reading of the indicator.

After you have connected the tester to the required power source, connect the indicator to the test unit. Cables are included with the tester for this purpose. Normally a table of cable usage is furnished in the applicable TO for the tester. This table lists the use of the cable and identifies the cable by the number stamped on a metal tag. This tag is attached to the cable. After the indicator is connected to the test set, position the switches of the tester as follows:

- Test selector switch..............SYN/IND
- Sync indicator switch.....................EZ
- Power-on switch ....ON

When the power-on switch is placed to the ON position, the indicator should assume the electrical zero position. This test is performed to insure that the indicator pointer has not slipped on the synchro rotor shaft. The electrical zero point of the indicator is identified by a white reference mark of the extreme outer edge of the indicator dial. If you can't find this reference mark, consult the indicator TO for the exact location. If, during an electrical zero check, the pointer does not align with the reference mark, the cover glass must be removed and the pointer reset to align the mark. In case the indicator is hermetically sealed, make sure your shop is authorized to disassemble this type of instrument before you make any attempt to repair it.

After you perform the electrical zero check satisfactorily, place the sync indicator switch to the CAL position. Now you are ready to continue with the scale error check of the indicator. As you should recall, the synchro transmitter of the tester is calibrated in degrees. The indicator will probably be calibrated in psi. For example, a setting of 64.5° on the synchro transmitter will cause the indicator to read 30 psi. The readings of the indicator must fall within the specified tolerances listed in the TO.

Remember that the test performed was typical and covered only one test that can be performed with the synchro tester. Other synchro components can be checked with this tester. The procedures for checking transmitters and other indicators can be found in the operating instructions TO for the tester.

Exercises (620):

1. You need to convert the reading of an indicator undergoing a test to the degree reading of the autosyn field tester. Where would the correct conversion information be given?

2. What is the purpose of performing an electrical zero check on a synchro indicator?

3. In what position is the sync indicator switch placed to comply with a scale error check on an indicator?

3-2. Fuel Flow

The fuel flow system measures the rate of fuel flow to the aircraft engines. This rate of flow is indicated in pounds per hour (PPH). The fuel flow indicating system is not absolutely essential for safe aircraft operation. However, it is that is extremely important in flight planning. The fuel flow system aids pilots in many ways. One of the most important ways is to aid them in establishing cruise control. If they know exactly how much fuel is being used by each engine, they can determine whether or not they have enough fuel to reach their destinations. The fuel flow system can also indicate an engine malfunction. This is done when the rate of fuel flow is either too high or too low for a given throttle setting. If the indication is too high for a particular throttle setting, that engine and total fuel consumption must be watched more closely. If the indication is too low, the pilot knows that the engine is not producing normal power.

621. Specify the operational characteristics and constructional features of fuel flow transmitters.

Fuel Flow Transmitters. You will find several variations of fuel flow systems and many types of fuel flow transmitters being used on today's aircraft. Even though their construction and appearance may differ, their operation is fundamentally the same. You understand, of course, that the transmitters must have some means of measuring the amount of fuel flow for a given period of time. This measurement occurs as the fuel flows through the transmitters. There are two connecting ports on the transmitter, clearly marked with arrows to show the direction of flow through the transmitter.

Single-Synchro Transmitters. Figure 3-5 shows a breakaway illustration of a single-synchro transmitter. The path of flow through the transmitter is shown by heavy black arrows. Notice that the fuel enters through the port facing you. Once inside the transmitter, the fuel flows through a chamber (E) called the metering chamber. The fuel then exits through the port away from you. As the fuel flows through the metering chamber, it applies force to the

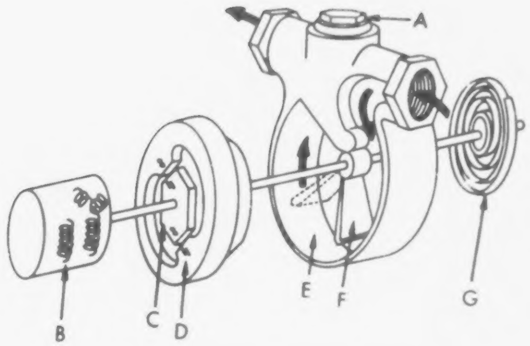

Figure 3-5. A typical single-synchro fuel flow transmitter.

moveable metering vane (F). Notice also in figure 3-5 that the metering chamber is not concentric in design. Because the chamber is not concentric, you can see that as the displacement of the vane increases, the area through which the fuel flows also increases. As more fuel flows through the transmitter, more force is exerted on the moveable vane; thus the displacement of the vane becomes greater.

Notice in figure 3-5 that the movement of the vane is restrained by a calibrated vane restraining spring (G). This spring dampens the movement of the vane and returns the vane to the NO FLOW position when the fuel flow stops. Attached to the opposite end of the vane shaft is a ring-shaped magnet (D). This magnet will rotate any time the vane moves. The movable vane, the calibrated spring, and the ring-shaped magnet are sealed within the fuel metering chamber.

Because the fuel-measuring section of the transmitter must be kept separated from the electrical section, a fueltight seal is placed over the ring-shaped magnet. This fueltight seal also contains the mounting frame for the synchro unit (B). Since we have sealed off the vane shaft, how is the rotor of the synchro unit moved? Look at figure 3-5. You will see a bar magnet (C) attached to the rotor shaft of the synchro unit. This arrangement is called a magnetic coupling. Even though a thin metal seal separates the two magnets, the bar magnet will align itself with the magnetic field of the ring magnet. When the ring magnet is rotated by the movable vane shaft, the bar magnet is repositioned and turns the rotor of the synchro unit. Depending upon the type of transmitter, the magnets previously discussed may be reversed. That is, the ring magnet may be mounted on the synchro rotor shaft, and the bar magnet may be mounted on the vane shaft.

As a safety precaution, the transmitter is equipped with a bypass relief valve (A). The valve is of the spring type and will open any time the rate of flow exceeds the flow limits of the transmitter. This valve allows fuel to bypass the measuring section and reach the engine should the moveable vane become stuck.

The synchro unit is electrically the same as the synchro units described earlier. The electrical connections between an indicator and this type of transmitter are shown in figures 3-1 and 3-2. The only significant difference is that the indicator dial is calibrated in pounds per hour instead of psi.

Multisynchro Transmitters. These are sometimes used on multiengine aircraft. The measuring section operates the same as the measuring section of the transmitter previously described. The electrical section is quite different because it includes the units necessary to operate a totalizer indicator. The units include an adjustable synchro transformer, moveable vane pinion gear, sector gear, linear synchro with pinion gear, synchro transmitter, and an auto transformer.

Multisynchro transmitters are designed to provide accurate indications on a nonlinear dial indicator. Because of this feature, the metering chamber is divided into two spirals. This means that the vane will move 130° to provide indications from zero (0) to 3,000 PPH. Then the final 48° of vane movement will provide indications from 3000 to 12,000 PPH. Thus, the total range of this transmitter is from 0 to 12,000 PPH. The vane movement is transferred from the vane pinion gear to the irregular-shaped sector gear. The sector gear meshes with the gears attached to the rotor of the synchro transmitter and the rotor of the linear synchro. When the vane moves, the rotor of both synchros will be displaced.

Synchro transmitter. The reason for using three different synchros may not be quite clear to you just yet. As we discuss each one separately, you will see their purpose. We will begin with the synchro transmitter. The synchro transmitter is a common synchro. It is used to transmit the fuel flow signal to the single-synchro indicator. An electrical schematic of the synchro hookup to the indicator is shown in figure 3-6.

Linear synchro. The linear synchro produces the signal that operates the totalizer indicator. The rotor of the linear synchro is energized with electrical power from the auto transformer or the aircraft power supply. The stator of the linear synchro is connected in the circuit. A signal ratio of 1 volt per 1,000 pounds of fuel flow must be maintained within the linear synchro. Only a small amount of rotor movement takes place when the rate of flow exceeds 3,000 PPH. Therefore, a means for stepping up the linear synchro signal output is necessary. This is done by a switch on the synchro transmitter. When the rate of flow exceeds 3,000 PPH, the switch changes positions. This allows a higher voltage to be applied to the rotor of the linear synchro. This voltage is supplied by the aircraft power supply.

Transmitter autotransformer. The autotransformer supplies the low excitation voltage to the linear synchro. The transformer is energized by 26-volt AC from the aircraft power supply. Locate the transformer within the transmitter shown in figure 3-6. Notice that, when the range switch is positioned to the right, a low excitation voltage will be supplied to the linear synchro from the center tap of the transformer. This low voltage is used for rates of flow from 0 to 3,000 PPH. As the rate of flow exceeds 3,000 PPH, the switch moves to the left and a higher voltage is applied to the rotor. This voltage is supplied through pin G of the transmitter connector. Trace the wire connected to G pin in figure 3-6. You will see that this voltage, after being dropped by a resistor, is applied to the left contact of the range switch. The switching of rotor excitation voltages is necessary to maintain the 1-volt-per-1,000-pound-per-hour ratio within the linear synchro.

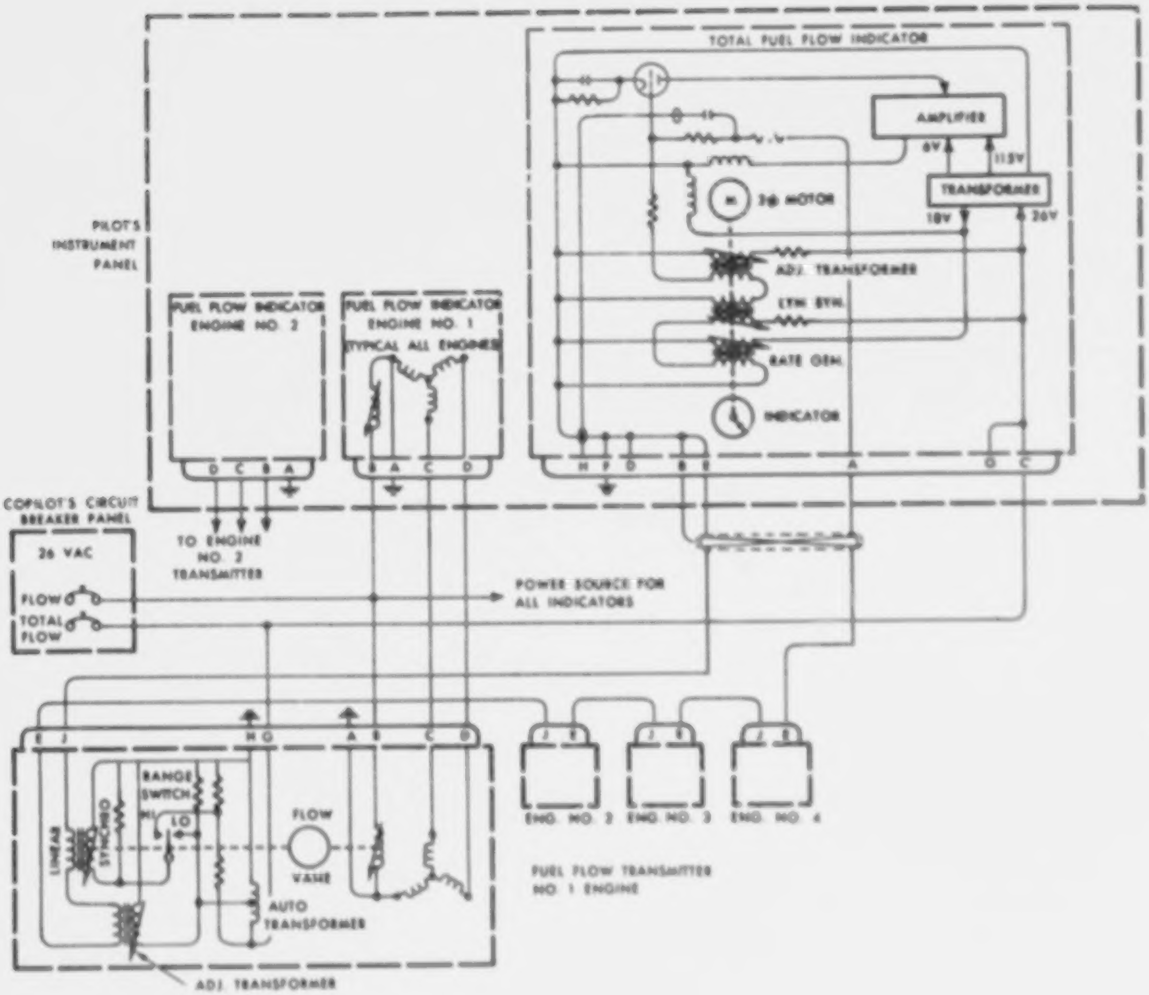
TOTAL FUEL FLOW INDICATOR
AMPLIFIER
6V
115V
TRANSFORMER
18V
26V
3Φ MOTOR
ADJ. TRANSFORMER
LYN SYN.
RATE GEN.
INDICATOR
PILOT'S INSTRUMENT PANEL
FUEL FLOW INDICATOR ENGINE NO. 2
FUEL FLOW INDICATOR ENGINE NO. 1 (TYPICAL ALL ENGINES)
COPILOT'S CIRCUIT BREAKER PANEL
26 VAC
FLOW
TOTAL FLOW
TO ENGINE NO. 2 TRANSMITTER
POWER SOURCE FOR ALL INDICATORS
RANGE SWITCH
HI
LO
LINEAR
SYNCHRO
FLOW
VANE
AUTO TRANSFORMER
ADJ. TRANSFORMER
ENG. NO. 2
ENG. NO. 3
ENG. NO. 4
FUEL FLOW TRANSMITTER NO. 1 ENGINE

Figure 3-6. Schematic of a fuel flow system circuit.

Transmitter adjustable transformer. The adjustable transformer is a synchro unit used only as a variable transformer in the circuit. When this synchro is installed upon assembly, the rotor is fixed and the synchro is adjusted to provide a zero signal output from the linear synchro when the transmitter is in a no-flow (zero) condition. Since only two legs of the stator are connected in the circuit, only two leads appear at the stator housing.

Exercises (621):

1. What is the purpose of the calibrated vane-retaining spring in a single-synchro fuel flow transmitter?

2. The rotor of the synchro unit is positioned in a single-synchro fuel flow transmitter by what?

3. The bypass relief valve in the fuel flow transmitter is necessary in the event of what?

4. What the rotors of the synchro units are positioned in a multisynchro fuel flow transmitter by?

5. The multisynchro transmitter metering chamber is divided into two spirals for what purpose?

6. What is the purpose of the synchro transmitter in the fuel flow transmitter?

7. What does the signal that operates the fuel flow totalizer indicator originate in?

8. What is the unit within the multisynchro fuel flow transmitter that allows a higher excitation voltage to be applied to the rotor of the linear synchro when the rate of flow exceeds 3,000 PPH?

9. What is the purpose of the adjustable transformer in the multisynchro fuel flow transmitter?

622. Identify the operating characteristics and construction features of fuel flow indicators and components.

Single-Synchro Indicators. The single-synchro indicators are typical synchro units. Their descriptions are the same as for the synchro indicators you have already studied. As you recall, the indicator consists of a synchro unit, a dial, and a pointer, all enclosed in a metal case. The dial is calibrated in pounds per hour of fuel flow. The range of the indicator is determined by the range of the transmitter with which it is to be used.

The indicator electrical connector has four pins. The four pins are used to connect the indicator to the transmitter by means of electrical wiring. A typical electrical hookup of the indicator to the transmitter is shown in figure 3-6. Notice that the synchro unit in the indicator is connected directly to the synchro transmitter in the fuel flow transmitter. If you have any further questions about the operation of this type of system, refer to the beginning of this chapter. A complete description of common synchro operation is given there.

The fuel flow system in some aircraft not only furnishes a fuel flow indication from each engine, it also furnishes, in some cases, a total fuel flow indication as well. The total fuel flow system is normally a separate circuit. Even if it should have a malfunction, the fuel flow indications to the single indicators would not be hampered. The multisynchro transmitter has the provisions for supplying total fuel flow indication.

Total Fuel Flow Indicator. This indicator consists of two synchro units, a motor-generator unit, an amplifier, and a gear train. Two pointers on the indicator indicate the total fuel flow in pounds per hour. The range of the indicator is from zero (0) to 100,000 PPH. An electrical schematic of a total fuel flow indicator is included in figure 3-6. You will see the indicator in the upper right-hand corner of the schematic. During the following description of the internal units, you must refer to the figure for proper unit location.

Signal amplifier. This amplifier receives and amplifies the signal from the linear synchros in the individual transmitters. This signal is applied to the grid of the triode tube. The tube is shown outside the amplifier block, but it is actually in the amplifier section.

Motor-generator unit. The motor-generator unit consists of a two-phase induction motor and a rate generator. The fixed phase of the motor receives its reference voltage from the autotransformer in the indicator. The control phase receives its voltage from the signal amplifier. The rate-generator fixed phase receives its reference voltage from the autotransformer also. The variable-phase output is used as a signal damping feedback signal to the amplifier.

Indicator autotransformer. The autotransformer is a multitap transformer that supplies the necessary voltages for indicator operation. The transformer receives its primary voltage from the aircraft power source (26 volts AC). Output voltages of 115, 18, and 6 volts AC are available from the transformer. The 115-volt output is supplied to the amplifier section along with the 6-volt output. The 18-volt output is supplied to the fixed phase of the induction motor and rate generator. Locate the autotransformer in figure 3-6. You will see the outputs to the units.

Linear synchro. The linear synchro is the signal nulling unit in the indicator. The rotor of the synchro is excited by 26-volt AC from the aircraft power source. This is applied through pin C of the electrical connector. The stator output signal is used to cancel the signal from the linear synchros in the transmitters. This signal is necessary to stop servoloop operation when the totalizer indicator reaches the proper indication.

Adjustable transformer. The adjustable transformer in the totalizer is used to adjust the output of the linear synchro to zero when the pointers are at zero. The adjustable transformer is a synchro unit with only two legs of the stator connected in the circuit. The rotor is excited by 26-volts AC from the aircraft power source. The stator is connected in series with the stator of the linear synchro. The rotor of this synchro is fixed when the synchro is installed at the factory, and it does not move. The synchro is then adjusted by moving the stator until a zero output is assured from the linear synchro.

Exercises (622):

1. Match the operational characteristics and construction features of fuel flow indicators/components listed in column A to their construction/operation listed in column B. Write the correct letter in the space provided. Some construction/operation items may not be used.

Column A

Components

- ____ (1) Single-synchro indicator.
- ____ (2) Total fuel flow indicator.
- ____ (3) Signal amplifier.
- ____ (4) Motor-generator unit.
- ____ (5) Indicator autotransformer.
- ____ (6) Linear synchro.
- ____ (7) Adjustable transformer.

Column B

Construction/Operation

a. Supplies two voltages to the signal amplifier.
b. Receives a signal from the linear synchro in the transmitter.
c. Mechanically connected to the indicator pointer.
d. Uses a slipring brush arrangement to prevent drag on the rotor.
e. The primary is connected to 26 VAC.
f. Provides a nulling voltage for the indicator.
g. Provides a variable-phase signal to the amplifier.
h. Measures PPH fuel flow with two pointers.
i. Receives electrical power from the indicator autotransformer.
j. Supplies a signal to the motor-generator unit.
k. Supplies 18 volts to the signal amplifier.
l. Receives a fixed phase voltage from the signal amplifier.
m. Has three voltage outputs.
n. Prevents indicator pointer oscillation.

623. Specify the operational characteristics of the common synchro fuel flow system and identify the functions of total fuel flow components.

System Operation. In the previous paragraphs, we described the components of a common synchro fuel flow system. You learned the units of each component and the purpose of each unit. As we proceed through the system operation, you may find it necessary to review some of the units. You have already learned the operation of the common synchro system. No further explanation of the circuit from the synchro transmitter to the individual indicator will be given. However, the operation of the totalizer system will be given in detail.

As you recall, the signal that operates the totalizer originates in the linear synchro of the transmitter. Notice in figure 3-6 that the signal output from the linear synchro, in fuel flow transmitter No. 1, appears across pins E and J of the electrical connector. Follow the wire from pin J of the transmitter. You will find that it is connected in series with the linear synchros of the other three engine fuel flow transmitters. Finally from pin E of transmitter No. 4, the signal is applied to pin A of the totalizer indicator. All of the transmitter linear synchros are connected in series. They form a signal summing circuit. This means that the total signal applied to pin A of the totalizer is the total of the signals produced by the linear synchros of all four transmitters.

With all necessary voltages applied to the fuel flow system, let's create a set of circumstances for our explanation of system operation. At this time, the transmitters are at a no-flow condition (engines not operating). No signal is being produced by the linear synchros. With this condition no signal is applied to the grid of the amplifier tube in the totalizer. The amplifier operates as a class B amplifier with the tube biased near cutoff. Therefore, no amplifier action is taking place. The pointers of the totalizer are at zero.

Let's start the No. 1 engine and see what happens. Fuel is now flowing through the transmitter. When the metering vane of the transmitter moves, it moves the rotors of the synchro transmitter and the linear synchro. The signal produced by the linear synchro is appled to pin A of the indicator. It then passes through two resistors, a connecting point, and onto the grid of the amplifier tube. The signal is then amplified and sent to the variable phase of the motor. The rotor of the linear synchro, the rate generator, and the pointers of the indicator are mechanically connected to the induction motor. The connection is shown in figure 3-6 by the black dotted line within the totalizer indicator. As the motor runs, it will drive the rate generator and reposition the rotor of the linear synchro and the indicator pointer.

In any servoloop-type circuit, there must be some means of canceling the input signal. If not, the motor will run continuously. The signal cancellation in this servoloop is done by the linear synchro in the totalizer indicator. The signal produced by the linear synchro in the indicator is always 180° out of phase with the signal from the transmitter. When the signal produced by the linear synchro in the indicator is of the same strength as the transmitter signal, the signal felt on the grid of the amplifier tube will be zero. With no signal felt on the tube grid, the amplifier action will stop. The motor will no longer run. The pointers of the indicator will now show the total fuel flow.

The rate generator, in the totalizer indicator, provides a damping feedback signal to prevent the indicator pointers from overshooting and oscillating as the servoloop is nulled. Notice figure 3-6. The variable phase of the rate generator is connected in series with the rotor of the linear synchro. As the rate generator turns, a voltage is produced by the variable phase. This voltage is 180° out of phase with the linear synchro rotor excitation voltage. The out-of-phase voltage will subtract from the rotor excitation voltage an amount proportional to generator speed. When the rotor excitation voltage decreases, the signal produced by the linear synchro will decrease. This keeps the motor from overspeeding and assures a smooth movement of the indicator pointers.

Figure 3-7 shows the phase relationship of the signals produced in the fuel flow system. The sine waves in Group 1 represent the following signals: sine wave A represents the reference voltage applied to the fixed phase of the induction motor; sine wave B represents the signal produced by the linear synchro in the indicator to cancel the transmitter signal (sine wave C) and null the servoloop. Remember that the signal that caused the indicator to drive upscale to indicate the fuel flow was in phase with the motor fixed-phase reference voltage.

Now the total fuel flow indicator shows the proper amount of fuel flow. Let's see what happens when the fuel flow decreases through the transmitter. Take a look at the sine waves shown in Group 2 of figure 3-7. Notice that the signal produced by the transmitter (sine wave C) has decreased by about 2 volts. This reduction in signal

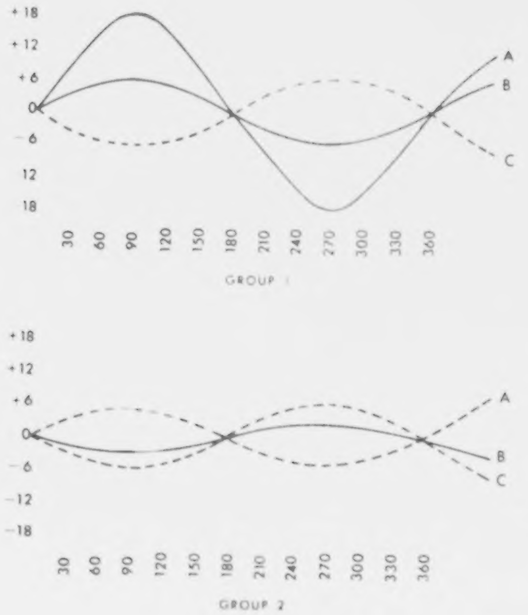

Figure 3-7. Phase comparison of fuel flow signals.

strength was caused by the decrease in fuel flow through the transmitter. The signal produced by the linear synchro in the indicator (sine wave A in this group) is still about 6 volts. The difference between these two signals (sine wave B, about 2 volts) is the signal that is now felt by the grid of the tube. Because this signal is 180° out of phase with the motor fixed-phase reference voltage (sine wave A, Group 1), the motor will turn in the opposite direction. As the motor runs, it will drive the pointers downscale. It also repositions the rotor of the indicator linear synchro. When the signal produced by the linear synchro decreases to about 4 volts, the servoloop will again be nulled. As the servoloop is nulled, the motor will stop. The indicator pointers will indicate the decrease in fuel flow.

Exercises (623):

1. Why the linear synchros of the fuel flow transmitters connected in series?

2. How is the rotor of the linear synchro repositioned in the total fuel flow indicator?

3. Referring to figure 3-7, explain when the motor in the totalizer indicator will stop running.

4. Match the components of the fuel flow system listed in column A with their functions listed in column B. Write the correct letter in the space provided. All the functions listed in column B need not be used.

Column A

Components

_____ (1) Transmitter linear synchro.
_____ (2) Totalizer amplifier tube.
_____ (3) Totalizer linear synchro.
_____ (4) Rate generator.

Column B

Functions

a. Produces a signal 180° out of phase with the totalizer linear synchro signal.
b. Prevents totalizer motor from running continuously.
c. Develops a two-phse output for operation of the totalizer two-phase motor.
d. Develops a total fuel flow signal.
e. Produces a signal 180° out of phse with the transmitter signal.
f. Provides a signal for operation of the totalizer two-phase motor.
g. Prevents pointer oscillation.

624. Specify the inspection and operational check procedures for the fuel flow system, and state the malfunction indicated by given hypothetical troubles.

Inspection, Operational Check, and Troubleshooting. Inspection requirements for the fuel flow system are the same as for the synchro systems. These requirements include such items as checking the components for security of mounting and overall condition of the wiring. Also check attaching fuel lines for evidence of leaks. If, during an inspection, you disturb any of the components or disconnect any electrical connectors in the system, you must perform an operational check of the system.

To adequately perform an operational check of the fuel flow system, the aircraft engines must be operated. The engines must, however, be operated by qualified personnel only. When these personnel operate the engines, they have a checklist to follow. By following the checklist, they can see if the fuel flow indicating system for each engine is indicating properly. With all engine fuel flow indicators showing a steady rate of flow, you can check the totalizer indicator for operation. For example, let's say that on a four-engine aircraft, all engine fuel flow indicators indicate 2,000 PPH. This means that the totalizer indicator should indicate 8,000 PPH. In the TO for the aircraft on which you are working, you will find a tolerance. This tolerance will vary with different aircraft, so always consult the applicable TO.

The maintenance required of the fuel flow system is basically the same as the maintenance of any synchro system. You must be able to detect a trouble in the system, as well as know the steps necessary to isolate the trouble. In the following paragraphs, we will discuss troubleshooting of the fuel flow components.

The troubles that are most common in the fuel flow system fall into two categories. They are identified as either a trouble in the individual engine indicating system or a trouble in the totalizer system. Let's begin with troubles in the individual engine indicating system. On an engine runup, it was noted that the fuel flow indicator for No. 3 engine was inoperative. The best method for checking the indicator is to switch the suspected indicator with one from another engine that you know is operating satisfactorily. If the indicating system then functions normally, you will know that the indicator that you removed was defective. If the system still does not operate normally, perform a wiring check from the indicator connector to the transmitter connector. Always consult the TO for the aircraft for the correct wiring hookup. If the check shows no defect in the wiring, then the trouble is most likely in the fuel flow transmitter. Most instrument shops are not set up to check fuel flow transmitters. You will, therefore, be required to replace the defective transmitter to complete your check of the system. Look back in figure 3-6 for a moment. You can see that the fuel flow indicator for engine No. 1 is connected directly to the synchro unit in transmitter No. 1. This connection is a simple synchro hookup. The same troubleshooting procedures can be applied to this system that we discussed for other simple synchro systems.

The trouble most common to the totalizer system is either an inoperative or an inaccurate totalizer indicator. A completely inoperative totalizer is usually caused by a defective indicator. You must, however, check the power input and the system ground before suspecting a defective indicator.

Look again at figure 3-6. Follow the wire connected to the bottom circuit breaker shown on the left side of the figure. You will find that this wire is connected to pin C of the totalizer indicator connector. Notice that F pin of the connector provides the ground lead for the totalizer indicator. If you place the leads of a voltmeter between pins C and F, the voltmeter should indicate 26 volts AC. If it does, this means that the wiring is not defective and that the indicator will probably have to be replaced. If the voltmeter indicates zero voltage, it means that the wiring or the circuit breaker is defective and must be repaired.

Errors in the totalizer indicator can be detected and isolated by running the aircraft engines. By starting the engines one at a time and checking to see that the totalizer indicates properly for each engine before starting another, you can pinpoint the defective transmitter. Let's say that the totalizer is indicating too high a total fuel flow. You would have the engine runup personnel start No. 3 engine and establish a flow rate of 3,000 PPH. The totalizer should also read 3,000 PPH. If the totalizer reads correctly, start the next engine. Establish a flow rate of 3,000 PPH on this engine, also. The totalizer should now read 6,000 PPH. At this point, imagine that the totalizer is reading 7,000 PPH. This would indicate that the linear synchro in the transmitter of the second engine is out of calibration, which means that the transmitter must be replaced. The same procedures can be used to isolate defective transmitters on other engines. It would be impossible to list all of the troubles that might occur in the fuel flow indicating system; therefore, we have discussed only the more common problems. If you follow these troubleshooting procedures, you should be able to isolate and repair any fuel flow system defects.

Exercises (624):

1. State the inspection requirements of the fuel flow system.

2. State the only adequate operational check of the fuel flow system.

3. Refer to figure 3-6. If the wire connected to pin B of No. 1 fuel flow indicator were open, how would it affect the indication on No. 1 indicator and the totalizer indicator?

4. Refer to figure 3-6. If the wire connected to pin C of the totalizer indicator were open, how would the indication of the totalizer indicator be affected? Why?

5. State the best method for troubleshooting an inaccurate totalizer indicator.

625. Differentiate between a common synchro system and a second-harmonic synchro system.

As stated at the beginning of our study of fuel flow systems, you will find many variations in these systems. Another type of fuel flow system is the second-harmonic type synchro system.

Second-Harmonic Type Synchro System. Figure 3-8 is a simplified diagram of a single system. It is strikingly different from the typical synchros you have studied thus far. The stators of the synchros are delta-wound instead of Y-wound, and power is applied to the stators instead of the rotors because the second-harmonic synchro uses a permanent magnet rotor. The rotor of the transmitter is mechanically positioned and thus held stable. The flux (lines of force) of the magnet interferes with current flow through each winding of the stator differently. This is due to its position in relation to each winding. This interference changes the shape (in effect, doubling the frequency) of the sine waves of the current flowing through the windings. When any outside source changes the shape of the sine wave, other frequencies are generated. The term "second harmonic" means that the frequency (cycles per second) is two times the basic frequency. Changing the shape of the sine wave also affects the magnetic field around the conductor (each winding). As you learned earlier in this course, current flow in each branch of a parallel circuit is the same. Therefore, because the indicator and transmitter are connected in parallel, the magnetic field created in the

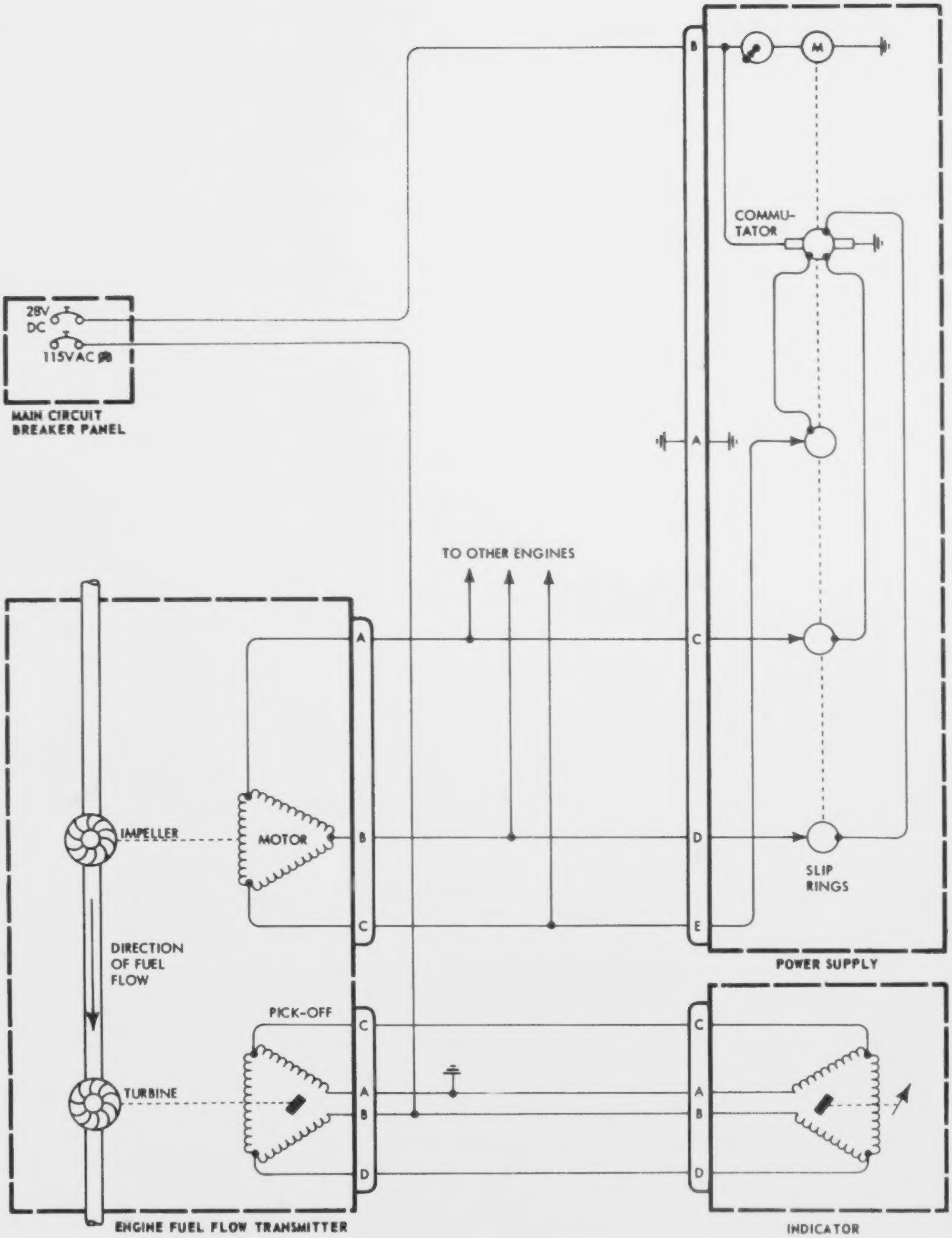
28V
DC
115VAC
MAIN CIRCUIT
BREAKER PANEL
B
M
COMMU-
TATOR
A
TO OTHER ENGINES
A
C
IMPELLER
MOTOR
B
D
SLIP
RINGS
C
E
DIRECTION
OF FUEL
FLOW
POWER SUPPLY
PICK-OFF
C
C
TURBINE
A
A
B
B
D
D
ENGINE FUEL FLOW TRANSMITTER
INDICATOR

Figure 3–8. Simple schematic of a second-harmonic type fuel flow system.

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transmitter is duplicated by the current flow in the indicator synchro. Thus, the free-moving permanent magnet rotor in the indicator synchro duplicates the alignment of the synchro transmitter.

The second-harmonic type synchro transmitter. In this type of transmitter, the fuel passes lengthwise through an impeller (see fig. 3-9) that is rotated by a constant speed motor. Forward fuel motion, plus the rotary impeller motion causes the passing fuel to swirl. The swirling fuel passes through a turbine which cannot rotate freely because of a restraining spring. Turning force against the turbine increases as fuel flow increases and results in partial rotation of the restrained turbine shaft. Up to 3,000 PPH fuel flow, the turbine shaft rotation is restricted by a single spring. At 3,000 PPH fuel flow, a second restraining spring "cuts in." When this happens, a considerable increase in fuel flow is required for further shaft deflection. Rotating with the turbine shaft is a permanent magnet. This moves within the field of a toroidally wound stator which is energized with 115-volt, 400-Hz, single-phase, AC power. The position of the permanent magnet within the stator field of the transmitter determines the signal fed to the harmonic repeater of the indicator. The stators of the fuel flow transmitters and indicators are energized from the same circuit breaker. The impeller drive motor uses a three-phase, 15- to 22-volt, 4-cycle, AC power. This is developed in a power supply unit which uses 28 volts DC.

Fuel flow power supply. The power supply converts 28-volt DC power into three-phase, 15- to 22-volt, 4-cycle, AC power by means of a motor and commutator assembly. The 28-volt DC power drives a constant speed motor and powers the input brush of the three-segment, motor-driven commutator as shown in figure 3-9. A ground-connected brush makes contact opposite to the input brush. Each segment of the commutator is connected to a separate slipring, permitting continuous pickup from each segment. Rotation of the commutator gives each segment a repeating cycle consisting of a "power contact," a "no contact," a "ground contact," and a second "no contact." Slipring brushes pick off the signals. Interaction with the transmitter motor yields a 15-to 22-volt, constant 4-CPS, three-phase, nonsinusoidal AC. The speed regulation of the motor in the power supply determines the accuracy of the output frequency. Since the speed of the impeller motor in the transmitter must operate at a constant, accurate speed, proper operation of the power supply is essential for accuracy of the system.

Harmonic repeater indicator. The indicator used with the second-harmonic synchro transmitter consists of a harmonic repeater whose permanent magnet position duplicates that of the synchronous transmitter in the fuel flow transmitter, a dial with a pointer, and, in some indicators, a signal generating system for a total fuel flow summation indicator. This dial, too, is calibrated in pounds per hour and the range is determined by the range of the transmitter with which it is to be used. The instrument dial is graduated in equal increments of 100 PPH through approximately the first two-thirds of the dial (see fig. 3-9) and in equal increments of 1,000 PPH through the remaining used portion of the dial. This provides high-accuracy fuel flow indications in the 0 to 3,000 PPH range and coarser readings above 3,000 PPH. This change in sensitivity is obtained through the use of the two restraining springs in the fuel flow transmitter, just as we studied. In addition to providing a visual indication of the flow rate to an engine, the indicator may provide a signal voltage, proportional to flow rate, to a fuel flow summation indicator. This signal, equal to 1 volt per 1,000 PPH of fuel flow, comes from a transformer energized potentiometer within the individual engine indicator. The potentiometer brush arm is coupled to the indicator pointer shaft, causing the "picked off" voltage signal to vary according to the position of the pointer. The construction of the potentiometer correctly proportions the signal throughout both the sensitive and coarse range of the individual indicator. To avoid error due to friction between the brush and potentiometer windings, the brush arm makes contact for only a short interval and is then released from the windings so that the indicator is free of that friction. A 4-CPS solenoid is used to produce this intermittent contact. The solenoid also operates a switch which grounds out the signal while the brush is free. All total fuel flow signals are connected in a series loop. Single-phase, 115-volt, 400-cycle power energizes the harmonic repeater and potentiometer transformer. The 15- to 22-volt, 4-CPS power from the power supply unit, which we previously discussed, energizes the 4-CPS solenoid in each individual indicator.

Summation indicator. The summation indicator has two pointers to indicate total fuel flow up to 120,000 PPH. The long, fast-moving pointer indicates 1,000 PPH for each numbered division of the scale, and the shorter, slower-moving pointer indicates 10,000 PPH for each numbered division of the scale. A servo-driven gear train positions the pointers and the brush arm of a followup potentiometer which provides an opposing voltage to null out the signal from the individual indicators. The incoming signal, in which 1 volt is equal to 1,000 PPH, is amplified to drive the servo motor to position the pointers. The servo amplifier consists of a DC power supply, a voltage amplifier, and an output stage of power amplification.

Exercises (625):

1. Define the term "second harmonic" as it relates to frequency.

2. In the second-harmonic fuel flow system, why is power applied to the stators instead of the rotors?

3. The common synchro fuel flow transmitter measures the mass (or volume) of fuel flowing through a nonconcentric chamber. How does the second-harmonic synchro fuel flow transmitter differ?

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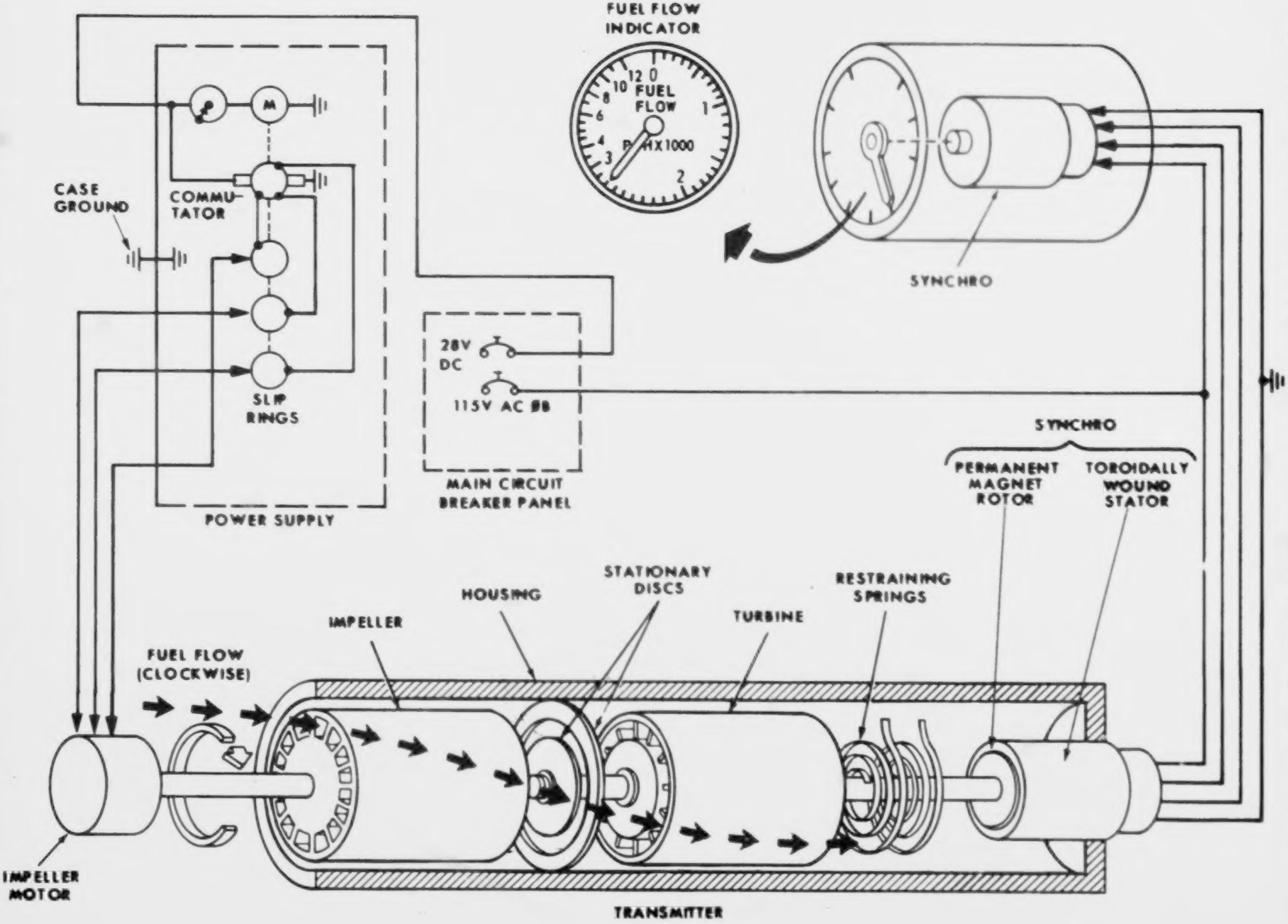
FUEL FLOW INDICATOR
12
0
10
8
6
4
3
1
2
FUEL FLOW
PPH X1000
SYNCHRO
CASE GROUND
COMMUTATOR
M
SLIP RINGS
POWER SUPPLY
28V DC
115V AC BB
MAIN CIRCUIT BREAKER PANEL
SYNCHRO
PERMANENT MAGNET ROTOR
TOROIDALLY WOUND STATOR
STATIONARY DISCS
HOUSING
RESTRAINING SPRINGS
TURBINE
IMPELLER
FUEL FLOW (CLOCKWISE)
IMPELLER MOTOR
TRANSMITTER

Figure 3–9. Illustration of a second-harmonic type fuel flow system.

4. What is used in the second-harmonic type fuel flow transmitter to provide accurate indications on a nonlinear indicator?

5. What is the purpose of the fuel flow power supply in the second-harmonic type of fuel flow system?

6. What is the source of the total fuel flow signal in the second-harmonic type system?

7. Why is 4-CPS power supplied to the individual indicator?

8. What causes the totalizer indicator to stop at the correct reading?

626. Cite procedural requirements for the removal and replacement of fuel flow system components.

Removal and Replacement. Some precautions are necessary when removing and installing any type of fuel flow transmitter. One of the first steps is to make sure that the fuel valves are closed so as to prevent fuel from gravity feeding to the engine on which you will be working. Next, pull and tag the circuit breakers for the valves and the affected systems. To further insure your safety and the safety of the aircraft and other personnel, remove all electrical power from the aircraft. This is a must because aviation fuel is easily ignited by a very small spark. You should also place danger tags on the battery switch and ground power receptacle. Disconnect the electrical connectors and fuel lines to and from the transmitter. Remove the fittings from the transmitter and keep them for reuse in the replacement transmitter, but remove and discard the seals. Then remove the transmitter mounting clamps and bonding wires. Note the direction of the arrow stamped in the housing of the transmitter and remove the transmitter. The replacement transmitter must be installed with the arrow pointing in the same direction. Remove the plugs and caps from your replacement (new) transmitter and install them on the transmitter you removed. Put new seals, coated with oil, on the fittings and install and torque the fittings in the inlet and outlet ports in the replacement transmitter. Position the transmitter on the mounting bracket, and install the mounting clamps and bonding wires. Then connect the fuel lines and electrical connectors. Safety wire the electrical connectors and torque and safety the tubing nuts, fittings, and mounting clamps. Do NOT safety the electrical connectors to a fuel, oil, or hydraulic line. Finally, perform an operational check as required in the aircraft TO.

Replacement of the fuel flow power supply units is normally quite simple although they are sometimes mounted in awkward places. The mounting of these units is unique compared to other instruments. Four threaded posts are brazed to the power supply case and are part of it. Hex-shaped, internally threaded extensions screw onto these posts and also attach to a shockmount assembly consisting of four rubber vibration isolators. This assembly is attached to the airframe. Replacement power supplies are not issued with the shockmount assembly. Good shockmount assemblies should be reused. Those that will not spring back to approximately their original position after being depressed and those with cracks in the rubber must be replaced. You can separate the shockmount assembly from the power supply using a 1/4-inch open end wrench, but this is more easily accomplished using a locally manufactured tool, which is shown in figure 3-10. A bonding wire attached to the shockmount assembly must be connected to the power supply case. As mentioned earlier, this is to eliminate noise in the aircraft radios and interphone systems. Unless otherwise specified by your aircraft TO, the electrical connector does not have to be safetied because it is shockmounted, is in a pressurized compartment, and is accessible during flight.

The general instrument removal and installation procedures, previously discussed, fully cover replacement of the fuel flow indicators. Even if a bench check of an indicator or power supply was made prior to installation in the aircraft, an operational check of the system is still required to insure that the aircraft is ready for operational use. For economical reasons, operational checks of fuel flow indicating systems should be done in conjunction with a required engine run. The engine(s) should not be run for this purpose alone.

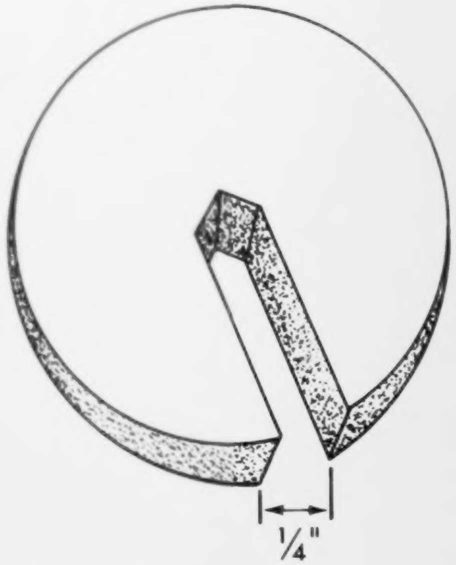

Figure 3-10. Silver dollar wrench for fuel flow power supplies.

Exercises (626):

1. List four preliminary steps required before replacing a fuel flow transmitter.

2. How should fuel flow transmitter seals be installed?

3. How do you determine which fuel line connects to the inlet port and which to the outlet port of the fuel flow transmitter?

4. What is the purpose of the bonding wire attached to the fuel flow power supply?

627. Identify the functions of given components of fuel flow systems test equipment.

Test Equipment. The synchro tester, previously discussed, is used to check common synchro fuel flow system components. The fuel flow system tester shown in figure 3-11 is also used to check common synchro-type components as well as some totalizer indicators. It can be used to check components on the aircraft as well as on the bench. This makes it an excellent troubleshooting aid. Neither of these testers can be used to check the second-harmonic type components or fuel flow power supplies.

This fuel flow system tester is a single unit tester housed in a metal carrying case. Mounted on the front panel are the units necessary to check the fuel flow system components. A space is provided on the right side of the tester to store test cables. These test cables are supplied with the tester.

The tester requires 26-volt, 400-HZ, single-phase, AC power for operation. When the tester is used on the aircraft, it receives its power through the test cables used to connect the tester to the fuel flow system. When used for bench testing the fuel flow components, a bench test power supply cable (supplied with the tester) can be used to connect it to the power source.

Notice in figure 3-11 that the tester has three switching arrangements. The first consists of a resistor-capacitor network, used to supply 12 calibrated AC signal voltages, when testing the total fuel flow system on the aircraft. This switch is labeled "linear transmitter circuit function" (K). The third switch sets up the tester for the various tests. This switch is labeled "test select" (J).

The tester has four indicators (see fig. 3-11), located on the front panel. They are the synchro transmitter (G), the linear indicator (F), the synchro indicator (D), and the voltmeter (M). The synchro transmitter is used to check individual indicators. When the transmitter is rotated to the degree points indicated by the calibration chart (E), the synchro transmitter furnishes a signal to the indicator under test. This signal is proportional to the angular displacement of the transmitter. The linear indicator is used as a total fuel flow indicator when testing the fuel flow system on the aircraft. A pushbutton low-scale switch (H) allows readings from the high-and-low scale of the linear indicator (F). The synchro indicator (D) is used as an individual engine indicator when checking the fuel flow system on the aircraft. This indicator has two calibrated dials. The outer dial is calibrated in degrees and has a range from 0° to 360°. The inner dial is calibrated in pounds-per-hour fuel flow and has a range from 0 to 12,000 PPH. The voltmeter is used in conjunction with the adjust-for-26-volts potentiometer (L) to adjust the voltage which is supplied to the transmitter to precisely 26 volts. This adjustment is necessary only when using the tester to check the fuel flow transmitter on the aircraft.

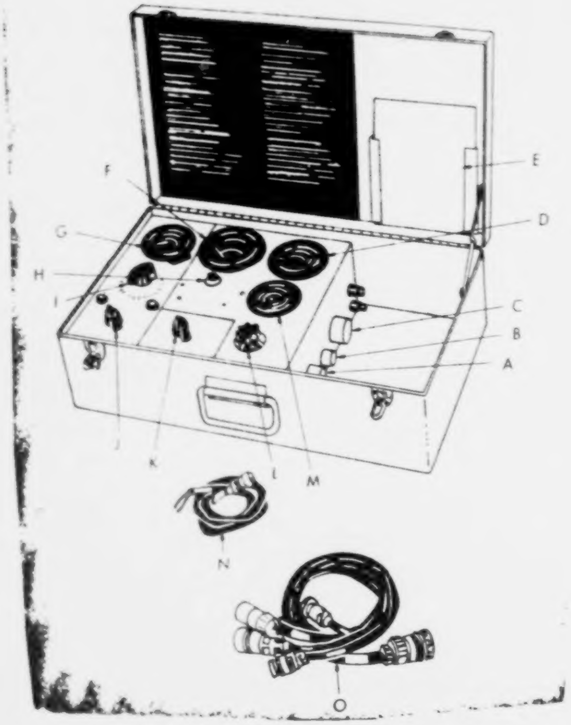

Figure 3-11. Common-synchro fuel flow system tester.

The electrical receptacles shown in figure 3-11 (A, B, and C) are used to connect the test cables to the tester. A detailed explanation of the use of the tester will be given during bench testing.

The MO-1 test set shown in figure 3-12 is used to check the second-harmonic type fuel flow system and components. It, too, is a portable test set which is contained in a case just like the tester you just studied. This tester, however, requires 115 volt, 400 cycle, single phase instead of 26 volts, and it must have 28 VDC when checking fuel flow power supplies.

Look at figure 3-12. The master transmitter (1) is used to ~~second~~ check the scale error of the flowmeter indicators of the second harmonic type. The transmitter may be set to any desired value by rotating the adjusting knob protruding

to test the F-1 total fuel flow indicator. This switch is labeled 'linear transmitter' (I). The second consists of a network used to supply three calibrated AC signal voltages.

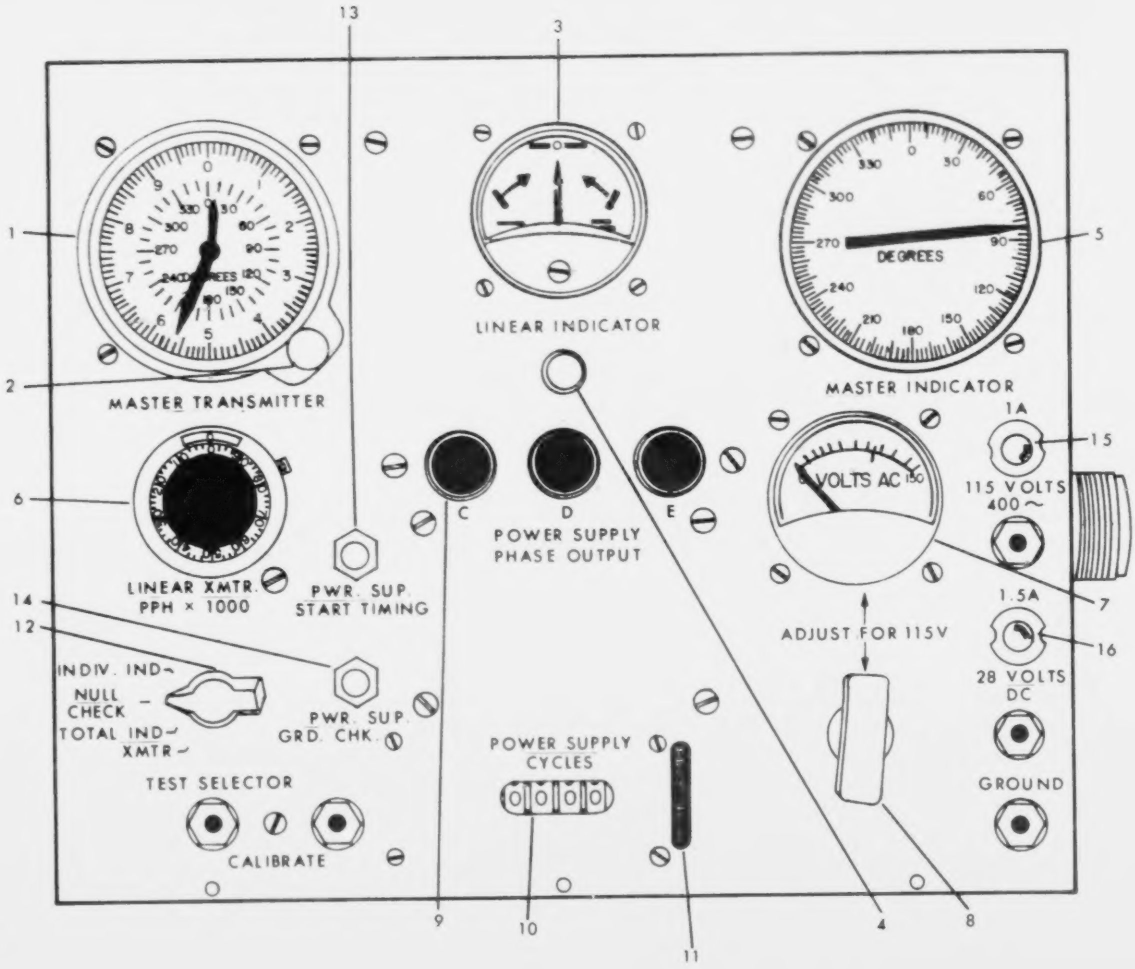
13
3
1
2
5
MASTER TRANSMITTER
LINEAR INDICATOR
MASTER INDICATOR
DEGREES
6
LINEAR XMTR.
PPH × 1000
PWR. SUP.
START TIMING
C
D
E
POWER SUPPLY
PHASE OUTPUT
VOLTS AC
1A
15
115 VOLTS
400 ~
7
1.5A
16
ADJUST FOR 115V
28 VOLTS
DC
GROUND
14
12
INDIV. IND
NULL
CHECK
TOTAL IND
XMTR
PWR. SUP.
GRD. CHK.
TEST SELECTOR
POWER SUPPLY
CYCLES
CALIBRATE
9
10
11
4
8

Figure 3–12. Second-harmonic fuel flow system tester (Type MO-1).

.1-degree intervals and major graduations at 1 degree intervals.

from the face of the instrument. The scale markings are in degrees; therefore, a calibration chart must be used to convert the readings to pounds per hour. The outer scale has minor graduations at The inner scale has minor graduations at 10-degree intervals and major graduations at 30° intervals.

The Master Indicator (5) is used to check the operation of fuel flow transmitters when they are installed in a system and to check their accuracy when they are mounted on a flow stand. The scale markings are also in degrees, with minor graduations at 2° intervals. The LINEAR XMTTR (transmitter) is used to check the scale error and operation of total summation indicators. It consists of a precision potentiometer with a dial that has inner graduations which correspond to .1 volt (100 PPH), and outer graduations which correspond to 10 volts (10,000 PPH). The transmitter output is a linear voltage of 0 to 100 volts, which corresponds to flow rates of 0 to 100,000 pounds per hour.

The linear indicator (3) is used to check the output voltage of individual indicators which have a signal generating section for a total fuel flow summation indicator. The master transmitter and the linear transmitter are used in conjunction with this indicator. The scale markings consist of a center mark and two end marks with arrows pointing towards the center mark. The accuracy of the indicator is not important since it is merely used to indicate a null condition. An adjustment is provided below the meter to balance the discriminator circuit so that a mid-scale read (?) will be obtained at null conditions.

The POWER SUPPLY CYCLES counter (10) and the POWER SUPPLY PHASE OUTPUT pilot lights (9) are used to check the frequency and output of the fuel flow power supply. The pilot lights indicate whether or not all three phases of the power supply output are present. The cycle counter, together wthh a 2-minute timer and an automatic relay network, is used to check the accuracy of the 4-CPS output. You must manually reset the cycle counter to zero before each test.

The TEST SELECTOR switch (12) sets up the tester for checking various parts. The PWR. SUP. START TIMING switch (13) starts the cycle counter. The PWR. SUP. GRD. CHK. switch (14) lifts the test set ground to the power supply being tested, thus making the power supply operate on its own ground (case ground). This checks the noise suppression capability of the system.

A 0- to 150-volt, 400-CPS voltmeter (7) and a variable autotransformer labeled "Adjust For 115 V" (8) are connected across the incoming power line to the test set, whether the power comes from the aircraft power system through the cables or from an external source through the 115-volts, 400-CPS post and the ground terminal post. By adjusting the variable autotransformer, ~~you can set~~ you can set the line voltage to 115 volts, as indicated on the volts AC meter, insuring correct line voltage for the test set itself and for the component being tested.

Exercises (627):

1. State the power requirements of the common synchro fuel flow system tester and the second-harmonic type fuel flow tester.

2. What is the purpose of the linear transmitter circuit/function on a fuel flow tester?

3. What is the purpose of the linear indicators used on both types of fuel flow testers?

4. The MO-1 fuel flow tester is used to check what type of fuel flow system?

5. What is the purpose of the adjustment provided for the linear indicator?

6. Match the components of the fuel flow systems test equipment listed in column A with their functions listed in column B. Write the correct number in the space provided. Some components have more than one function listed, and some functions will not be used.

Column A

Components

____ (1) Synchro transmitter.
____ (2) Phase lights.
____ (3) Pushbutton low-scale switch.
____ (4) Voltmeter.
____ (5) Counter.
____ (6) Eight-pin female connector.
____ (7) Calibration charts.
____ (8) Variable auto-transformer.
____ (9) Linear transmitter.
____ (10) Synchro indicator.

Column B

Functions

a. Allows for low-and-high scale readings on the linear indicator.
b. Insures that 115 volts is applied to the test set.
c. Displays degrees and PPH.
d. Its output signal is proportional to its angular position.
e. Simulates a total fuel flow indicator when making a check on the aircraft.
f. Shows phase rotation of power supply output.
g. Shows number of cycles in a 2-minute interval.
h. Connects the totalizer indicator to the test set.
i. Aids in adjusting exactly 26 volts to the transmitter.
j. Simulates an individual indicator.
k. Furnishes a signal to individual indicators.
l. Convert degrees to PPH.

628. Specify procedures for bench checking fuel flow system components.

Bench Checks. Bench testing, using the synchro tester, has already been explained. In this section, we will discuss bench testing an individual fuel flow indicator and a totalizer indicator by use of the common synchro fuel flow system test set. Then we will discuss the bench check of a fuel flow power supply by use of the second-harmonic type fuel flow system test set. We will not cover bench checking a fuel flow transmitter because they cannot be checked without a flow test [illegible]stand. Fuel flow test stands are normally found only at depot repair facilities.

Individual engine fuel flow indicator. The procedures listed here are examples of a typical test. Always consult the TO for the tester you are using to learn detailed procedures. To check the individual engine fuel flow indicator, proceed as follows:

(1) Connect the test cable (0, fig. 3-11) to the tester through the indicator receptacle (A, fig. 3-11).

(2) Connect the indicator to the four-pin female connector of the test cable (0, fig. 3-11).

(3) Connect the power cable (N, fig. 3-11) to the tester through the power receptacle (B, fig. 3-11).

(4) Connect the power cable to a source of 26-volt, 400-Hz, single-phase, AC power. (CAUTION: Because both pins A and B of the power receptacle are grounded, do NOT reverse polarity.)

(5) Set the test select switch (J, fig. 3-11) to the SYN-25100 position.

(6) Turn on electrical power to the tester.

(7) Rotate the pointer of the synchro transmitter (G, fig. 3-11), using the small knob in the lower right corner, to the degree setting listed in the calibration chart (E, fig. 3-11).

(8) The readings of the indicator under test should agree with the synchro transmitter settings as shown on the calibration chart.

Totalizer indicator. To bench check the totalizer indicator, these steps must be followed:

a. Repeat steps a, c, and d of the previous paragraph.

b. Connect the totalizer indicator to the eight-pin female connector of the test cable (0, fig. 3-11).

c. Set the test select switch to LINEAR-36750.

d. Turn on electrical power to the tester.

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e. Rotate the linear transmitter switch (1, fig. 3-11) through its various positions.

f. The readings of the indicator under test should correspond to the numerical settings of the linear transmitter switch.

Power Supply. To bench check the fuel flow power supply using the MO–1 tester, follow these steps:

a. Connect the main cable to the test set connector, which is in the cable storage bin. Connect the other end of the main cable to the required adapter cable. Then connect the adapter cable to the power supply.

b. Connect 28-volt DC power to the power input binding posts. Insure that the correct polarity is observed. The three green lights marked "power supply phase output" should alternately light in a D-C-E sequence. This indicates that the power supply is operating, all three phase have output, and phase rotation is correct.

c. Set the counter marked "power supply cycles" to zero.

d. Press the pushbutton marked PWR. SUP. START TIMING; then release it. In about 25 seconds, the counter will start to record the power supply cycles. It will stop automatically at the end of a fixed 2-minute interval. If the power supply is operating at the correct speed, the counter will read 480 at the end of the 2-minute interval. Sixty seconds per minute for two minutes times 4 cycles per second equals 480 cycles.

e. External grounding of the power supply is not necessary for correct power supply operation, but it is required for radio noise suppression. When checking a power supply, you must ground the case before you do the next check.

f. Press the test set button marked PWR. SUP. GRD. CHK. The phase output lights D–C–E on the test set should not dim and the repetition rate of lighting should not change. If the power supply case is not properly grounded, the power supply will not run, and the phase lights will not light. You can do a timing check with the PWR. SUP. GRD. CHK. button held down to verify the repetition rate.

You must remember to consult the TO for the aircraft or for component under test to learn accepted tolerances for the readings. Remember, also, that you can use the fuel flow tester to check the fuel flow components on the aircraft as well as on the bench. The step-by-step procedures for testing the system on the aircraft varies with different aircraft. Therefore, we will make no attempt here to discuss these tests. Again, we remind you to consult the applicable aircraft TO.

Exercises (628):

1. Which component of a fuel flow system normally cannot be bench checked in a field shop? Why?

2. To what degree setting do you rotate the pointer of the synchro transmitter when you are checking an individual indicator?

3. When you are bench checking a total fuel flow indicator, what should the readings of the indicator under test correspond to?

4. When bench checking a fuel flow power supply, what precaution should you observe when applying power to the test set?

3-3. Variable Reluctance Pressure System

The variable reluctance pressure (VRP) system is used on several Air Force aircraft to measure engine oil pressure. This system's operating principle differs somewhat from that of the synchro pressure system. However, it is still considered an engine instrument system. You, as an avionics instrument system specialist, are required to maintain this system. In the following paragraphs, we will discuss the system components, operating principles, troubleshooting, bench check procedures, and removal and installation procedures as they pertain to the variable reluctance pressure system. The system consists of an indicator, a transmitter, and the electrical wiring necessary to connect the two components. The first component we will discuss is the pressure indicator.

629. Specify operational characteristics of the variable reluctance pressure indicator and transmitter and differentiate between dynometer and D'Arsonval meter movements.

Indicator. The VRP indicator is essentially a dynamometer-type, moving-coil, AC voltmeter. The dynamometer type meter movement is very similar to the D'Arsonval meter movement that you studied earlier in the electronic principles volume. The main difference is that the permanent magnet used in the D'Arsonval meter movement is replaced by fixed coils. These coils serve as electromagnets. With its permanent magnet replaced by electromagnets, the meter movement will measure AC without using a rectifier circuit.

So that you may better understand the construction and operation of the dynamometer meter movement, let's review the construction and operation of the D'Arsonval meter movement. As you recall, the D'Arsonval meter movement contains a permanent magnet. This magnet furnishes a magnetic field to react with the magnetic field produced by the moving coil. The magnetic field of the permanent magnet will always have the same polarity. In other words, the north pole and the south pole of the magnet will never change. The polarity of the magnetic field around the moving coil will never change, as long as current flows through the moving coil in the same direction. So the magnetic polarity between the permanent magnet and the magnetic field of the moving coil will never change. Now it should be easy for you to see that, if AC is applied to the moving coil of the D'Arsonval meter, its magnetic field reverses polarity for each half-cycle of the applied AC. This causes the meter to oscillate up and down scale with each alternation of the AC.

In the dynamometer meter movement, the permanent magnet is replaced by electromagnets (fixed coils). See figure 3-13. Now, when AC is applied to the fixed coils, their magnetic polarity changes for each half cycle of the AC. The moving coil is wound so that its magnetic polarity is always the same as the fixed coils. So for each half cycle of the applied AC, the magnetic polarity between the fixed coils and the moving coil remains the same. In effect, we have the same situation as was necessary for the D'Arsonval meter movement to operate.

As you know, like poles of magnets repel, and unlike poles attract. If the magnetic field of the moving coil is placed inside the magnetic field of the fixed coils, the fields attempt to align themselves. It is the interaction of these magnetic fields, that causes the meter pointer to be deflected. When no current is flowing through the moving coil, no magnetic field is present around the coil. The pointer of the indicator is held at zero by the spring tension of the hairsprings (fig. 3-13. There is a moving coil that is mounted in the center of the fixed coils. The moving coil is free to rotate within the fixed coils. This moving coil has the pointer of the indicator connected to the center shaft. Whenever current flows through the moving coil, the coil rotates because of the interaction of the magnetic fields. As the moving coil rotates, it moves the pointer upscale.

The dynamometer has a moving coil that aids in containing the magnetic field of the fixed coils. It also prevents external magnetic fields from causing errors in the indicator. There are two thermistors that keep current in the circuit stable regardless of temperature changes.

Transmitter. The VRP transmitter consists basically of a pressure-sensing diaphragm, two coils, an armature, and a compensating diaphragm. (See fig. 3-14.) The components

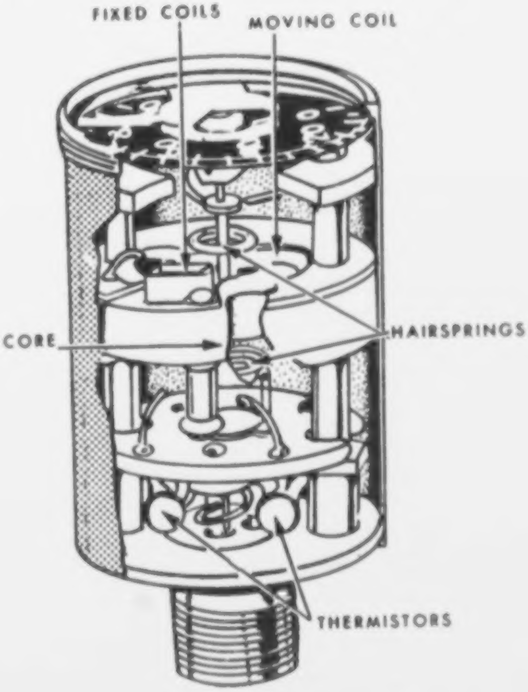

Figure 3-13. Variable reluctance indicator.

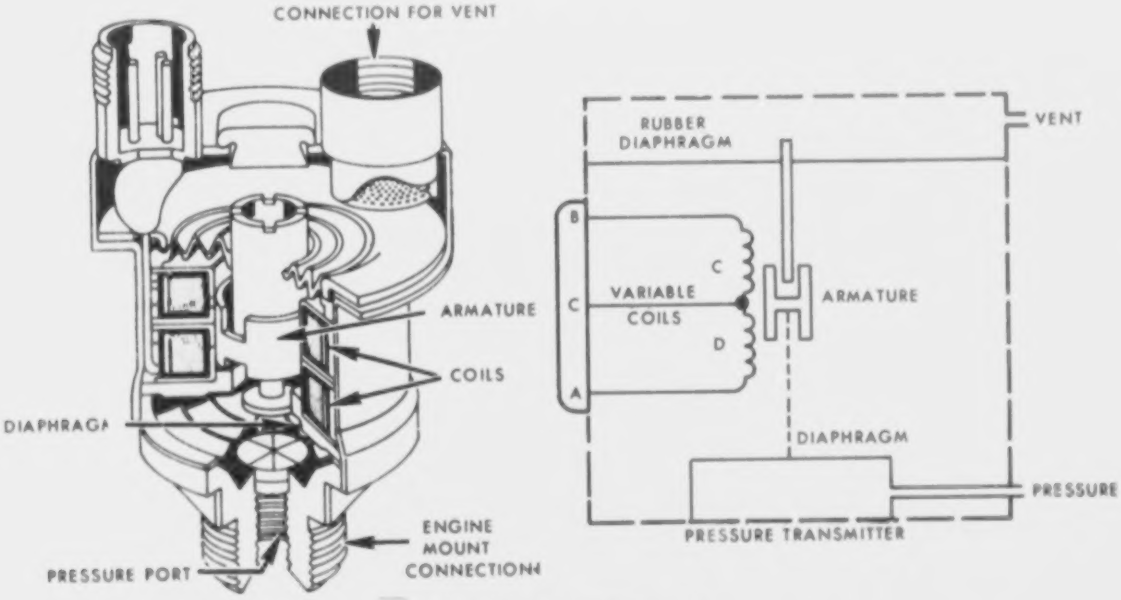

Figure 3-14. Variable reluctance transmitter.

are housed in a sealed case and cannot be replaced. An opening in the top of the transmitter allows adjustment of the transmitter on the bench. The transmitter is mounted directly to the engine by the engine mount connection. In actual installation on the engine, an O-ring seal is placed around the engine mount connection to prevent oil leakage.

The transmitter operates on the principle of varying the reluctance to the magnetic lines of flux surrounding the coils within the transmitter. You should remember that the inductance of a coil can be changed. This is done by providing a path of high or low reluctance to the magnetic lines of flux surrounding the coil. One way to do this is to insert a core into the center of the coil. This core provides a lower path of reluctance to the magnetic lines of flux than an air core. The amount of inductance change depends on the permeability of the material and how far the material is inserted into the coil.

The armature is connected to the pressure-sensing diaphragm at the bottom of the transmitter. When pressure is sensed by the diaphragm, the diaphragm expands. This expansion changes the armature position within the coils. The armature is made of a material that has high permeability. As the armature is moved inside the coils, it offers a path of lower reluctance to the magnetic lines of flux than the path offered by the air gap. This path of low reluctance, provided by the armature, causes the inductance of the coils to vary with armature position.

The vent connection is on top of the transmitter. It is usually connected to atmospheric or engine internal pressure. The transmitter measures the differential pressure between the oil pump output and the reference pressure connected to the vent connection.

Exercises (629):

1. Why is the dynamometer meter movement used in the indicator of the VRP system?

2. State the main difference between the dynamometer meter movement and a D'Arsonval meter movement.

3. What causes the moving coil of a dynamometer meter movement to move?

4. Describe the basic operation of a variable reluctance pressure transmitter.

5. Which unit within the variable reluctance pressure transmitter ~~that~~ causes the inductance of the fixed coils to change? How does it do so?

630. Specify operational characteristics of the variable reluctance pressure system.

System Operation. The electrical units of the VRP system are connected to form an AC bridge circuit. An electrical diagram of a typical variable reluctance system is shown in figure 3-15. The required system power, 26 volts AC, is applied through pin B of the transmitter and indicator. Pin A of the indicator and transmitter electrical connectors serves as the common lead, or ground, for the circuit. The wire connected to pin C is the signal-carrying lead.

Electrically, fixed coils A and B of the indicator are connected in series. They both have the same inductive reactance or opposition to current flow. From your studies of electrical circuits you should be able to see that fixed coils A and B will drop the applied AC voltage equally. For

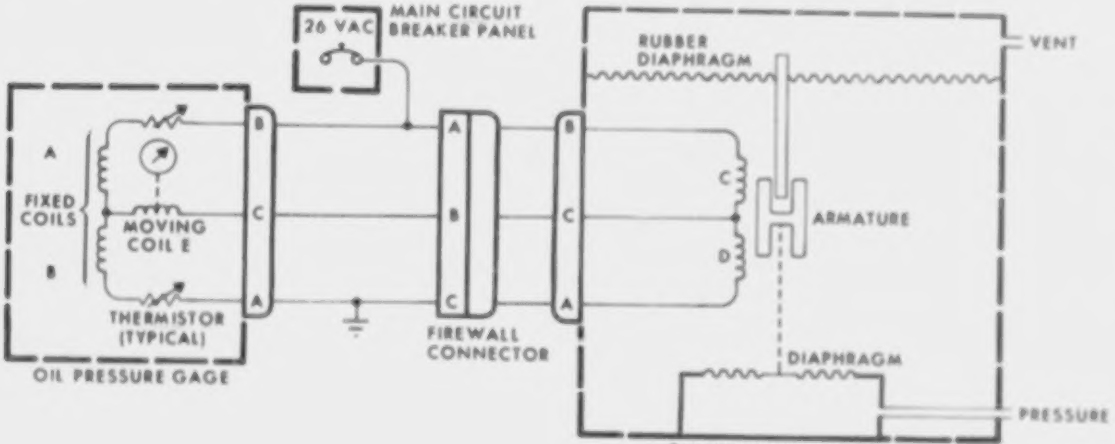

Figure 3-15. Variable reluctance pressure indicating system.

example, the applied voltage shown in figure 3-15 is 26 volts AC. Thus, fixed coils A and B will have an equal voltage drop of 13 volts.

When the armature of the transmitter is centered, as shown in figure 3-15, it affects the variable coils C and D equally. The coils are caused to have the same inductive reactance and drop the applied voltage equally. This means that the variable coils C and D, have an equal voltage drop of 13 volts. When the voltage drops across coils A, B, C, and D are equal, the bridge circuit is balanced. No current will flow through the moving coil E. At this time, the pointer of the indicator is on zero.

When pressure is applied to the diaphragm of the transmitter, the armature moves upward. This movement causes the inductive reactance of variable coils C and D to change. The voltage drops across coils C and D are no longer equal. The bridge circuit is unbalanced. Current now flows through moving coil E. This causes the pointer of the indicator to be deflected upscale. For example, let's say that the armature moves upward enough to cause the voltage drop across coil C to go up to 16 volts. Since the armature is also having an effect on coil D, the voltage drop across coil D goes down to 10 volts. Now let's assign polarities to the voltage drops across the coils for a given half cycle; the voltage drops across the coils from top to bottom are as follows: coil A, +13 volts; coil B, +13 volts; coil C, +16 volts; and coil D, +10 volts. Under these conditions, current will flow through coil E because the top of coil B is at a +13-volt potential. The top of coil D is at a +10-volt potential in reference to ground. Since +10 volts is more negative than +13 volts, current flows from the +10-volt potential to the +13-volt potential through coil E in the indicator.

On the negative half cycle of the applied AC, all the polarities of the coils reverse. However, the voltage drop across the coils never changes unless the armature is repositioned. This completes our discussion of the VRP system.

Exercises (630):

1. How are the fixed coils are electrically connected in a VRP indicator?

2. Refer to figure 3-15. When coils A, B, C, and D have the same inductive reactance, what is the condition of the bridge circuit?

3. What condition in the variable reluctance bridge circuit will cause current to flow in the moving coil of the indicator? What action will cause this condition?

631. Specify inspection, removal and installation, and operational check procedures, and match troubles in the VRP system with their causes.

Inspecting, Removing and Installing, Operationally Checking, and Troubleshooting. The inspection procedures for the VRP system are the same as those described earlier for synchro systems. If you should need a review of these procedures, you can find them in the previous sections of this chapter.

The transmitter of the VRP system is mounted directly to the engine. This makes it impossible to use a portable pressure standard to perform an operational check of the system on the aircraft. The engine must be operated when an operational check is necessary. Remember that the engine must be operated by qualified personnel only. Once the engine is running, you must check the indicator for the proper indications as prescribed by the applicable aircraft TO.

If you discover a faulty indication, you are responsible for troubleshooting and repairing the VRP system. Therefore, let's see what steps you will follow in troubleshooting the system.

The most common trouble that occurs in the VRP system is either a high or low indication. Of course, this condition can be caused by a defective transmitter or indicator. However, the problem can also be caused by a faulty vent system to the transmitter. The transmitter is designed to measure differential pressure. So, the connections to the vent (or reference pressure) are of great importance. A leak or obstruction in the vent line or fittings can cause improper indications. For example, if the vent line is connected to engine internal pressure, the transmitter will measure the difference between the oil pump output and the engine internal pressure. So you can see that, if a leak in the vent line to atmospheric pressure occurs, the transmitter would no longer measure the difference between oil pump output and engine internal pressure. Depending upon the value of the engine internal pressure, a leak of this type could cause the indicating system to read high or low. Improper indications caused by leaks or obstructions in the vent lines to the transmitter are most noticeable, especially if the aircraft ascends or descends in altitude. When you are required to troubleshoot a high or low indication, make sure the vent system is in serviceable condition. This must be done before suspecting a defective transmitter or indicator.

A fluctuation in most systems of this type is considered normal. The TO for the aircraft on which you are working will specify the amount of fluctuation that is acceptable. For example, one aircraft TO states that a fluctuation of ± 5 psi is allowable. Most other troubles that occur in the VRP system can be isolated by performing wiring checks. Remember to consult the applicable TO for the aircraft on which you are working for the correct wiring connections.

On an aircraft that has more than one VRP system installed, you can cross-check components to aid in troubleshooting. When you suspect an indicator to be unserviceable, you can switch it with one that you know is serviceable. The easiest way is to switch it with one from another engine position. However, since the transmitter is connected directly to the engine, it will have to be replaced with a serviceable unit if it is found to be defective. So make sure that the rest of the system is in serviceable condition before you replace the transmitter.

In the preceding paragraphs, we have discussed troubleshooting the VRP system without the aid of test equipment, except for the multimeter. There is a test set available for the VRP system; and if your shop has this tester, it can be a valuable aid in troubleshooting the system. You must observe the standard instrument maintenance practices that you studied at the beginning of this volume when removing and installing the components of this system. Remember, the indicator should be range marked for the type of aircraft it is being installed in. Always use a properly lubricated, new O-ring when installing a transmitter. The typical location of the transmitter on the engine, as shown in figure 3-16, requires the use of a crowsfoot extension for its removal and installation. The transmitter should normally be torqued to 350 to 400 inch-pounds; therefore, you should carefully compute your torque wrench setting prior to installation.

Exercises (631):

1. What are the inspection requirements of the VRP system?

2. What are the requirements of an operational check of a VRP transmitter?

3. What are the most common problems that occur in the VRP system?

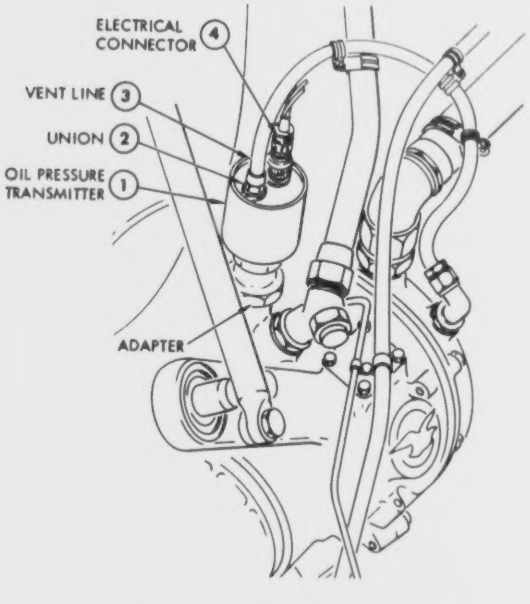

Figure 3–16. Installation of a VRP oil pressure transmitter.

4. Match the troubles of the VRP system listed in column A with their probable causes listed in column B. Write the correct letter in the space provided. Some probable causes are used more than once and some are not used.

Column A

Troubles

_____ (1) High indication.
_____ (2) Low indication.
_____ (3) Inoperative indication.
_____ (4) Excessive fluctuation.
_____ (5) High indication caused by excessive external temperature.

Column B

Probable Causes

a. Defective circuit breaker.
b. Defective transmitter.
c. Defective bearings.
d. Defective pressure line.
e. Defective indicator.
f. Improperly adjusted transmitter.
g. Defective wiring.
h. Ruptured transmitter pressure diaphragm.

632. Specify the correct test equipment and bench check procedures to use for the VRP components.

Test Equipment. The tester designed to be used with the VRP system is a type TTU 26/E test set. The tester provides the means for testing the installed system on the aircraft. When used in conjunction with a pressure standard (deadweight tester), the TTU 26/E can also be used to bench check the system components. The test set is mounted in a portable metal carrying case. The case contains an instrument panel and storage space for the test cable supplied with the tester.

The instrument panel of the tester contains the switches, indicators, and necessary electrical receptacles for tester operation. A voltmeter and frequency meter are provided for checking the system power. The master indicator is used as a standard against which the calibration of the transmitter is checked. An indicator percentage (%) deflection switch is provided for simulating the transmitter output signals when checking the indicator. This switch has marked control settings for every 10 psi increase from 0 to 100 psi. When used in conjunction with the master indicator switch, the percentage deflection switch can also be used to test the master indicator of the test set. A binding post allows connection of a bench power source to the tester. A knob is provided to allow adjustment of the power source to precisely 26 volts. Fuses provide protection for the tester circuits. The components to be tested are connected to the tester through the indicator and transmitter receptacles by using the correct test cable.

An operating instructions plate is provided on the inside of the tester lid. The instruction plate gives step-by-step instructions for operating the tester on the aircraft and on the bench. The TTU 26/E test set is relatively easy to use. Since testing of the system can be done by following the step-by-step procedures listed in the TO for the tester, we will cover only the bench checks that can be performed with the TTU 26/E test set.

Bench Check. Use the procedures listed in the following paragraphs when bench checking a VRP transmitter. You must use pressure standard (deadweight tester) in conjunction with the TTU 26/E test set to perform this test. The deadweight tester is necessary to supply a known pressure to the transmitter. Check the TO for a review of the procedures to follow when preparing the deadweight tester.

The deadweight tester was also covered in the chapter on direct reading pressure gages.

To prepare the tester for use, comply with the following steps:

(1) Connect the tester to a 26-volt, 400-Hz power source, using the binding post.

(2) Turn the volts adjust knob to cause the voltmeter to indicate 26 volts.

(3) Check the frequency meter to insure a frequency of 400 Hz ± 10 cycles.

(4) Push the master indicator check switch in the direction of the arrows on the tester panel.

(5) Hold the master indicator check switch in the direction of the arrows. Then turn the indicator percentage deflection switch from point to point. This procedure checks the accuracy of the master indicator.

To perform a bench check on a VRP transmitter, do the following:

(1) Mount the transmitter to be tested to the deadweight tester in a vertical position.

(2) Connect the transmitter to the tester, using the proper test cable. (CAUTION: the insulating cap must be installed on the connector of the test cable not in use. This prevents the possibility of electrical shock to the tester operator.)

(3) Check the voltmeter and frequency meter for indications of 26 volts, 400 Hz.

(4) Set the indicator percentage deflection switch to zero.

(5) Check the master indicator for zero. This is done by pushing the master indicator check switch in the direction of the arrows.

(6) Release the master indicator check switch.

(7) With zero pressure applied to the transmitter, check the master indicator for a reading of zero. It must read within the specified tolerances listed in the applicable TO for the transmitter you are checking.

(8) Repeat steps (d) through (g), applying pressure to the transmitter, for each succeeding test value. These are marked on the indicator percentage deflection switch.

If the transmitter under test does not perform within the tolerances listed in the TO, you must adjust the transmitter. Remove the small plate in the top center of the transmitter. Then insert the special spanner-type adjusting wrench into the armature, and turn the wrench to adjust the armature. Turning the adjusting wrench clockwise decreases the indicator reading. Turning the adjusting wrench counterclockwise increases the indicator reading. Remember to perform a complete bench check of the transmitter after any adjustment.

Exercises (632):

1. What type of test set is used to test the VRP system?

2. What are voltmeter and frequency meter on the variable reluctance test set used for?

3. What indicator is used as a standard when checking the calibrations of the VRP tester?

4. What is the range of the percentage deflection switch?

5. What [illegible] test unit that must be used with the VRP test set to bench test a variable reluctance pressure transmitter?

6. What must you do if the VRP transmitter does not perform within the tolerances listed in the TO?

CHAPTER 4

Thrust Measurement Systems

SOME OF THE MORE important factors considered in the design of an aircraft are speed, range, and reliability. A combination of several different things determine these qualities. One of the most important is how efficiently the engine performs. Today's aircraft have several instruments installed to monitor engine performance. One of the most important systems is the engine pressure ratio (EPR) system.

On early aircraft, engine horsepower was estimated from the readings taken from the tachometer, manifold pressure gage, and—if the aircraft were so equipped—the torque gage. On early jet engines, tachometer and engine pressure gage. On early jet engines, tachometer and engine temperature readings were used to estimate the engine thrust (horsepower). On the later jet engines, that have two compressors which operate independently of each other, it was found that a slight variation in rpm would produce a large variation in thrust. So, again, the need for an instrument system that would give the pilot an accurate indication of the power available became apparent. This brought about the development of the engine-pressure ratio (EPR) system. Extensive testing and experimenting revealed that the thrust produced by a jet engine is directly proportional to the ratio between air pressure at the front of the engine (inlet) and exhaust pressure at the rear of the engine. This gives us the engine-pressure ratio system that gives the pilot an accurate indication of the thrust being produced by the engine.

4-1. Engine Pressure Ratio System

Tachometer, fuel flow, and exhaust gas temperature indications give the pilot indications of engine efficiency. The power output of the engine can only be estimated from these indications. The only accurate method of determining the thrust produced by a jet engine is to measure the ratio of engine inlet pressure to engine exhaust gas pressure. The engine pressure ratio system provides a direct indication of the ratio between the two pressures.

Since EPR is an accurate means of determining the thrust produced by a jet engine, the indicator in the cockpit is a valuable aid to the pilot. By observing the EPR indications, the pilot can fly the aircraft more efficiently and safely. From performance charts in the flight manual, the pilot can determine the takeoff pressure ratio. By setting the power level to obtain this EPR, the pilot is assured of having the proper thrust for takeoff. On multiengined aircraft, the pilot can set the same EPR on all engines to maintain engine thrust balance. These are only two examples of the many ways the pilot uses the EPR system. From these examples, you can see that the EPR system must function accurately at all times. It is your job to maintain the EPR system. For this reason, you must have a thorough knowledge of the system components, operation, and maintenance procedures.

633. Specify the operational characteristics of the EPR system components.

Description. One of the most widely used EPR systems is discussed in this section. This system is referred to as the capacitance pickup system. The system consists of a transducer that is connected to pressure lines from the engine. A synchro indicator is located in the cockpit. The transducer changes mechanical motion into electrical signals. These are transmitted to the indicator for presentation as units of EPR (numbers). Of course, there is more to the system than this. Let's discuss each part of the system separately. To begin with, review briefly the pressure sources and methods of connection.

Pressure probes and connectors. As you recall, engine pressure ratio is determined by comparing one source of pressure to another. These two pressures are the inlet (Pt_2) and exhaust (Pt_7) pressures of the engine. These are measured at predetermined locations on the engine. The locations vary on different aircraft. You will need to consult the aircraft TOs for exact probe locations. The inlet pressure probe is usually located on the inlet of the engine. From the port, tubing feeds the inlet pressure to the inside of the transducer case as shown in figure 4-1.

The exhaust pressure probes are located in the exhaust section of the engine. There may be six or more of these probes evenly spaced around the exhaust case so as to obtain an accurate pressure measurement. They are connected to the exhaust port of the transducer mounting rack with steel tubing. From this port the tubing feeds the exhaust pressure through the sealed transducer case to a pressure bellows inside the transducer. The Pt_7 pressures have been contaminated by burned gases. This method of connecting the pressure bellows to the exhaust port keeps these undesirable exhaust gases out of the transducer case. Figure 4-1 illustrates a typical EPR system.

Transducer. A transducer consists of a mechanical-sensing device (sealed metal bellows), a servoloop, and two transmitting synchros mounted in an airtight case. The transducer is permanently attached to a shock-resistant mounting rack as shown in figure 4-2. The mounting rack serves as a connecting point for the pressure and electrical connections.

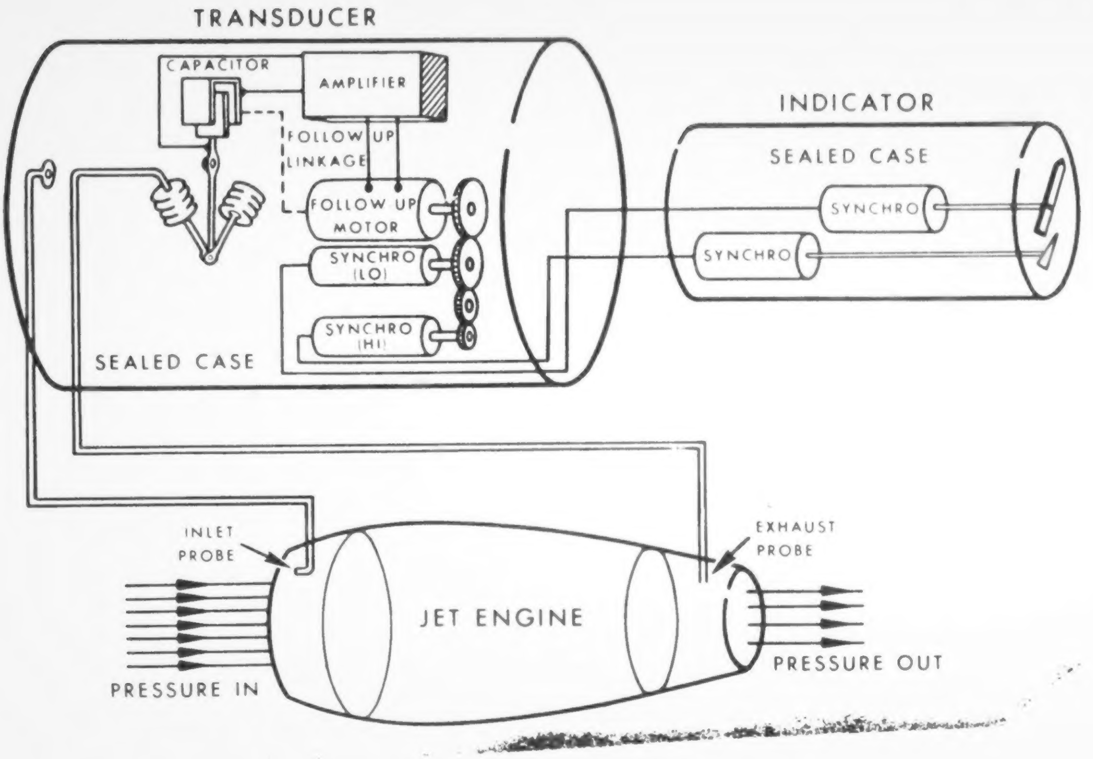
TRANSDUCER
CAPACITOR
AMPLIFIER
FOLLOW UP
LINKAGE
FOLLOW UP
MOTOR
SYNCHRO
(LO)
SYNCHRO
(HI)
SEALED CASE
INDICATOR
SEALED CASE
SYNCHRO
SYNCHRO
INLET
PROBE
EXHAUST
PROBE
JET ENGINE
PRESSURE IN
PRESSURE OUT

Figure 4–1. Engine pressure ratio (thrust indicating) system.

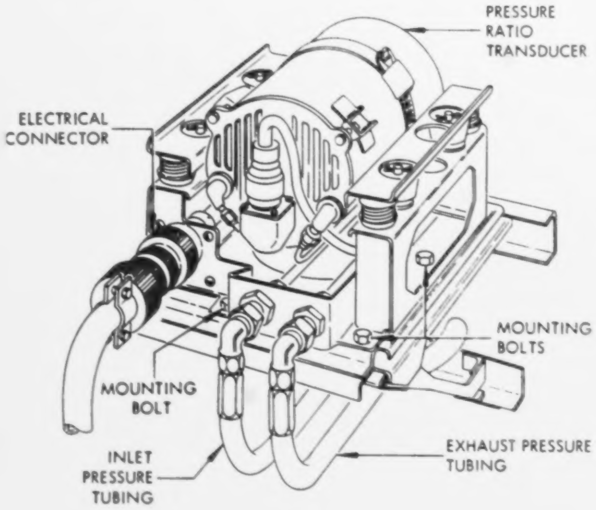
PRESSURE
RATIO
TRANSDUCER
ELECTRICAL
CONNECTOR
MOUNTING
BOLTS
MOUNTING
BOLT
INLET
PRESSURE
TUBING
EXHAUST PRESSURE
TUBING

Figure 4–2. EPR transducer installation.

The mechanical-sensing device consists of a dual bellows assembly and the mechanical linkage needed to transmit their movements to the error-signal sensing element, either a balanced beam mechanism or a variable capacitor.

One of the bellows is evacuated and sealed and is used to sense inlet pressure applied inside the transducer case. Exhaust pressure is applied to the inside of the other bellows. The two bellows and their connecting linkage form a differential pressure sensing mechanism. Figures 4-1 and 4-3 have simplified illustrations of this assembly.

There are two types of EPR transducers that you will find used on a great variety of aircraft. In one type of transducer, intake and exhaust pressures operate sealed metal bellows. The mechanical forces from the bellows act on a balanced beam mechanism as shown in figure 4-3. If the pressure ratio changes, an unbalanced condition is detected by an E-core transformer which develops an error signal for the amplifier. Output of the amplifier drives the servo motor to cause a compensating movement of the balance mechanism fulcrum carriage. A pressure-operated switch increases the gain of the amplifier at high altitudes. The servo motor is geared to two transmitting synchros that provide the electrical output of the transducer.

The other type of transducer has a variable capacitor, as shown in figure 4-4, which is acted upon by the bellows. When the center plate of the capacitor is moved, an error signal is applied to an amplifier. Output of the amplifier drives a servo motor which positions the outer plates of the

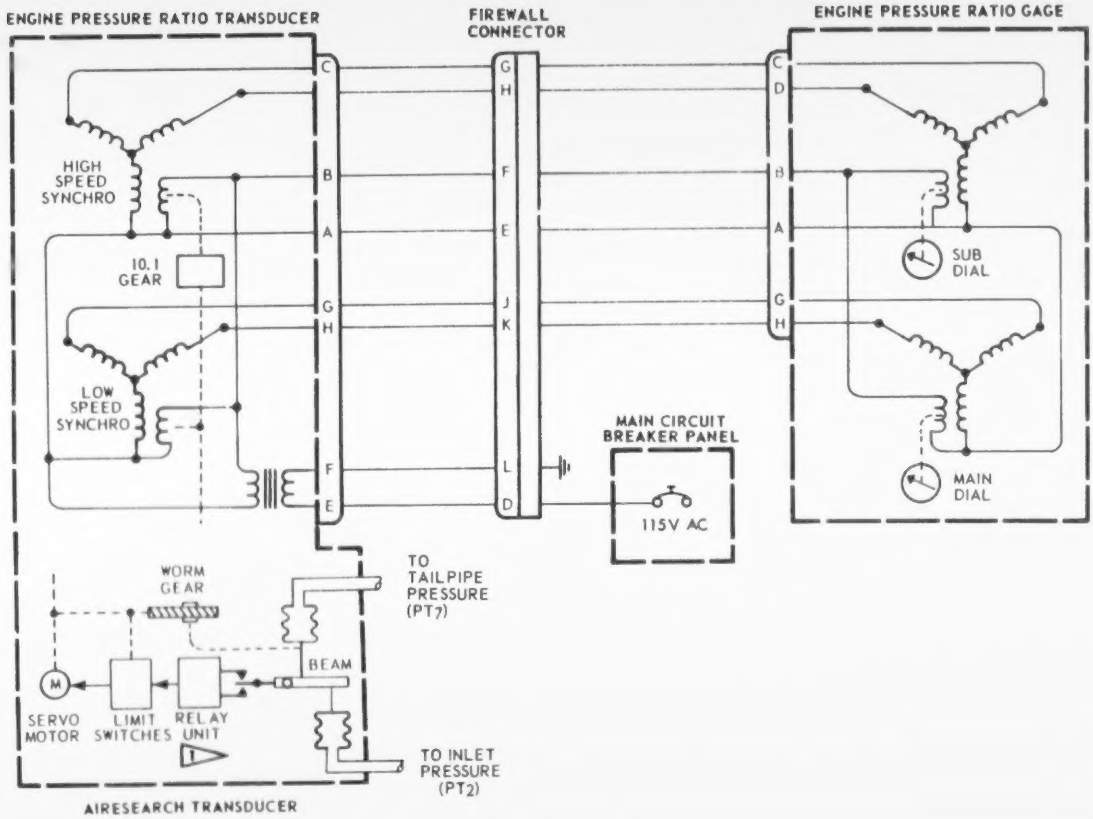
ENGINE PRESSURE RATIO TRANSDUCER
FIREWALL CONNECTOR
ENGINE PRESSURE RATIO GAGE
C
B
A
G
H
F
E
G
H
F
E
J
K
L
D
C
D
B
A
G
H
HIGH SPEED SYNCHRO
10.1 GEAR
LOW SPEED SYNCHRO
SUB DIAL
MAIN DIAL
MAIN CIRCUIT BREAKER PANEL
115V AC
WORM GEAR
TO TAILPIPE PRESSURE (PT7)
BEAM
M
SERVO MOTOR
LIMIT SWITCHES
RELAY UNIT
TO INLET PRESSURE (PT2)
AIRESEARCH TRANSDUCER

Figure 4-3. Inductance-type transducer in an EPR circuit.

capacitor to null out the error signal. The servo motor is also geared to the transmitting synchros. Power is supplied to the transducers at 115 volts AC from breakers on the main circuit breaker panel. Except for the method of developing the error signal and physical appearance, the transducers are the same and are interchangeable on many types of aircraft.

The servoloop consists of a variable capacitor or an E-core transformer, an amplifier, and a motor generator unit. The signal-sensing unit is either a variable capacitor or an E-core transformer. The amplifier is a class A amplifier. It has two stages of amplification and a discriminator section. The motor, through mechanical linkage, positions the rotors of the two transmitter synchros and the outer plates of the variable capacitor or balance mechanism fulcrum carriage to cancel the input signal. The two transmitting synchros are similar in construction and operate the same as the synchro units discussed previously. One of the synchros (hi speed) is used to operate a small vernier pointer on the EPR indicator. The other synchro (low speed) is used to operate the larger pointer. We have briefly described the purpose of each of the units in the transducer. Compare figures 4-1, 4-3, and 4-4, and you will be able to see the connection between and similarity of the units. The synchro signals from the transducer operate the engine pressure-ratio gage.

Indicator. The indicator used with both types of transducers has two pointers, each driven by a synchro unit as shown in figures 4-1 and 4-4. The main pointer indicates within a pressure range from 1.2 to 3.4 units EPR. The main dial is graduated in increments of .1. A subdial pointer makes one complete revolution for each graduation on the main dial. This vernier dial divides each main scale division of .1 into 10 parts; therefore, each increment of the vernier dial is worth .01. The two receiver synchro units of the indicator are similar and operate the same as the synchro units previously discussed. The case of the indicator is sealed.

Exercises (633):

1. How is the thrust of a jet engine measured?

2. What is Pt$_2$ and Pt$_7$?

3. What is the purpose of the EPR transducer?

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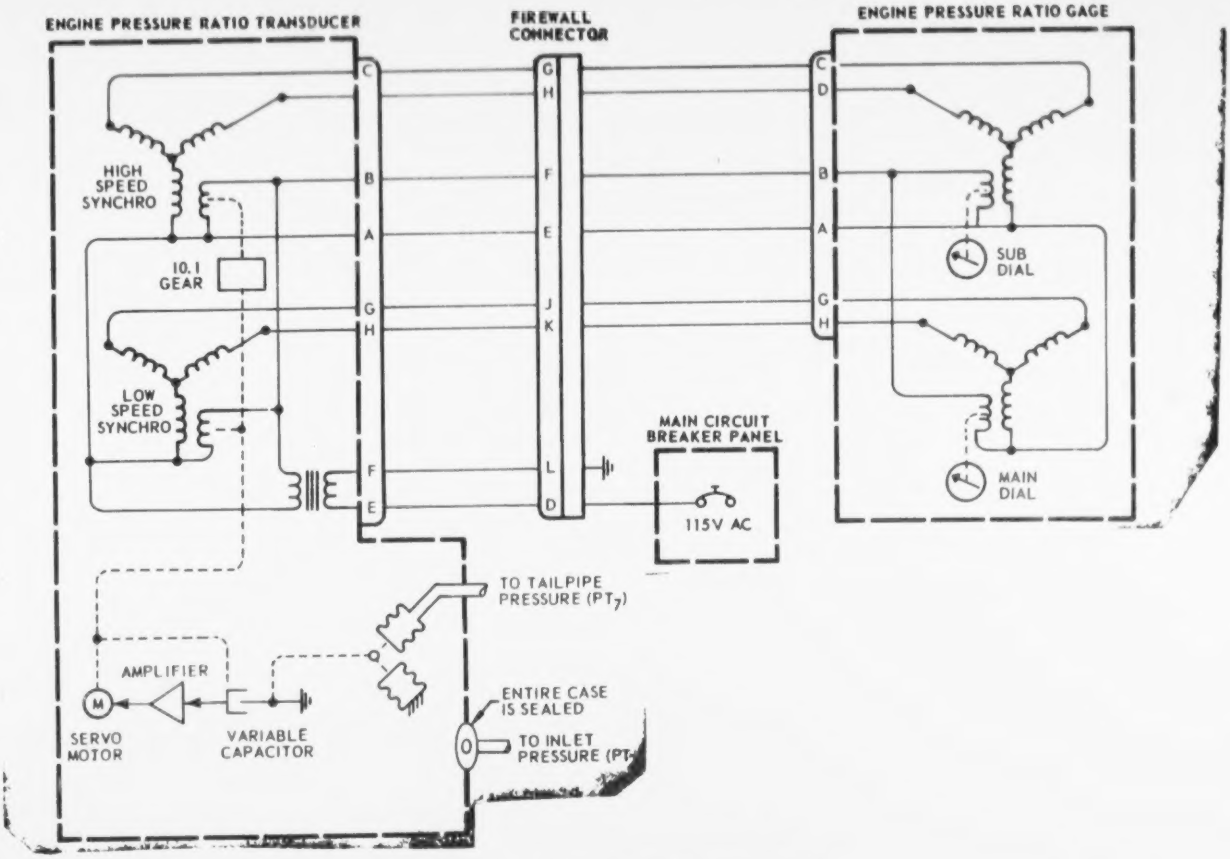

ENGINE PRESSURE RATIO TRANSDUCER
FIREWALL CONNECTOR
ENGINE PRESSURE RATIO GAGE
HIGH SPEED SYNCHRO
10.1 GEAR
LOW SPEED SYNCHRO
C
B
A
G
H
F
E
G
H
F
E
J
K
L
D
C
D
B
A
G
H
SUB DIAL
MAIN DIAL
MAIN CIRCUIT BREAKER PANEL
115V AC
TO TAILPIPE PRESSURE (PT7)
ENTIRE CASE IS SEALED
TO INLET PRESSURE (PT
AMPLIFIER
M
SERVO MOTOR
VARIABLE CAPACITOR

Figure 4–4. Capacitance-type transducer in an EPR circuit.

4. What is the EPR transducer servoloop?

5. What is the purpose of the vernier dial on the EPR indicator?

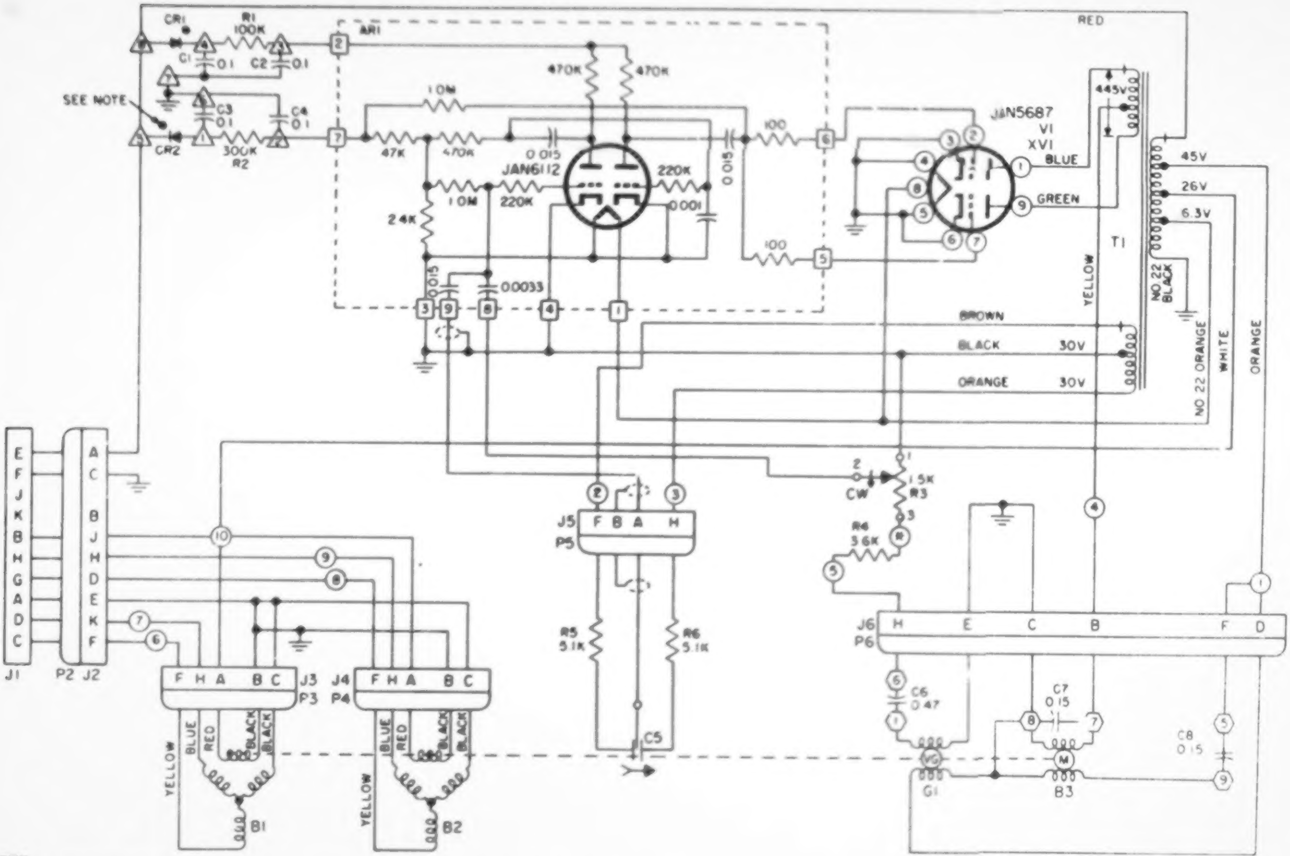
634. Complete statements concerning power applications in the EPR indicating system.

Power Sources. In our discussion of system operation, we will use the capacitive pick-up transducer only. Refer to figures 4-5 and 4-6 aswe discuss it. The EPR system receives 115-volt, 400-Hz, single-phase, AC power from the aircraft power source. This power is applied to the transducer only. It is applied through pin E of the transducer mounting rack electrical connector (J1). (fig. 4-5). The power is then fed through pin A of the transducer case electrical connector (J2) to the rectifier circuits in the upper left-hand corner of the diagram. The rectifier circuit containing CR2 provides the grid biasing voltages for the amplifier (JAN 6112) and discriminator (JAN 5687) tubes. The rectifier circuit containing CR1 provides plate voltage for the amplifier tube.

Notice that, from terminal 8 in the upper left corner of figure 4-5, the 115-volt AC power is applied to the primary of transformer T1. This transformer provides the AC voltages necessary for system operation. The 45-volt tap of T1 provides the fixed-phase reference voltage for motor (B3) and the velocity generator (G1). Follow the wire connected to the 26-volt tap of T1. You will find that it is connected to the rotors of both synchro units (B1 and B2). At terminal 10, located just above synchro unit B1, the 26-volt power is applied to pin J of connector J2 and to pin B of connector J1. From connector J1, the 26-volt power is supplied to the rotors of the synchro units in the indicator. The remaining 6.3-volt tap of T1 provides the heater voltage for the amplifier and discriminator tubes.

Transformer T1 has two secondary windings. Study figure 4-5. Notice that the top secondary winding of T1 provides the plate voltage to discriminator tube JAN 5687. The bottom secondary winding provides the operating voltage to the AC capacitance bridge circuit.

Now we have operating voltage applied to all the units of the system. Let's trace a sensed signal through the system. When the engine is not running, both the inlet pressure bellows and the exhaust pressure bellows sense the same


CR1
R1
100K
AR1
RED
C1
.01
C2
.01
SEE NOTE
C3
.01
C4
.01
CR2
300K
R2
470K
470K
1.0M
47K
470K
0.015
JAN6112
220K
0.015
100
JAN5687
V1
XV1
445V
BLUE
GREEN
45V
26V
6.3V
T1
1.0M
220K
2.4K
.001
100
0.015
0.0033
YELLOW
NO.22 BLACK
BROWN
BLACK
30V
ORANGE
30V
NO.22 ORANGE
WHITE
ORANGE
1.5K
R3
CW
R4
3.6K
J5
P5
F B A H
R5
5.1K
R6
5.1K
C5
J6
P6
H E C B F D
C6
0.47
C7
0.15
C8
0.15
G1
B3
J1
P2
J2
E F J K B H G A D C
A C B J H D E K F
J3
P3
J4
P4
F H A B C
YELLOW
BLUE
RED
BLACK
BLACK
B1
B2

NOTE:
ALL RESISTANCES ARE IN OHMS AND ALL CAPACITANCES ARE IN UF UNLESS OTHERWISE SPECIFIED.
(*) STANDOFF TERMINAL ON TB4
● DOT ON RECTIFIER IDENTIFIES CATHODE TERMINAL
>→ MOVEMENT OF CENTER CAPACITOR PLATE FOR INCR PRESSURE RATIO.

Figure 4–5. Schematic of a capacitive EPR transducer.

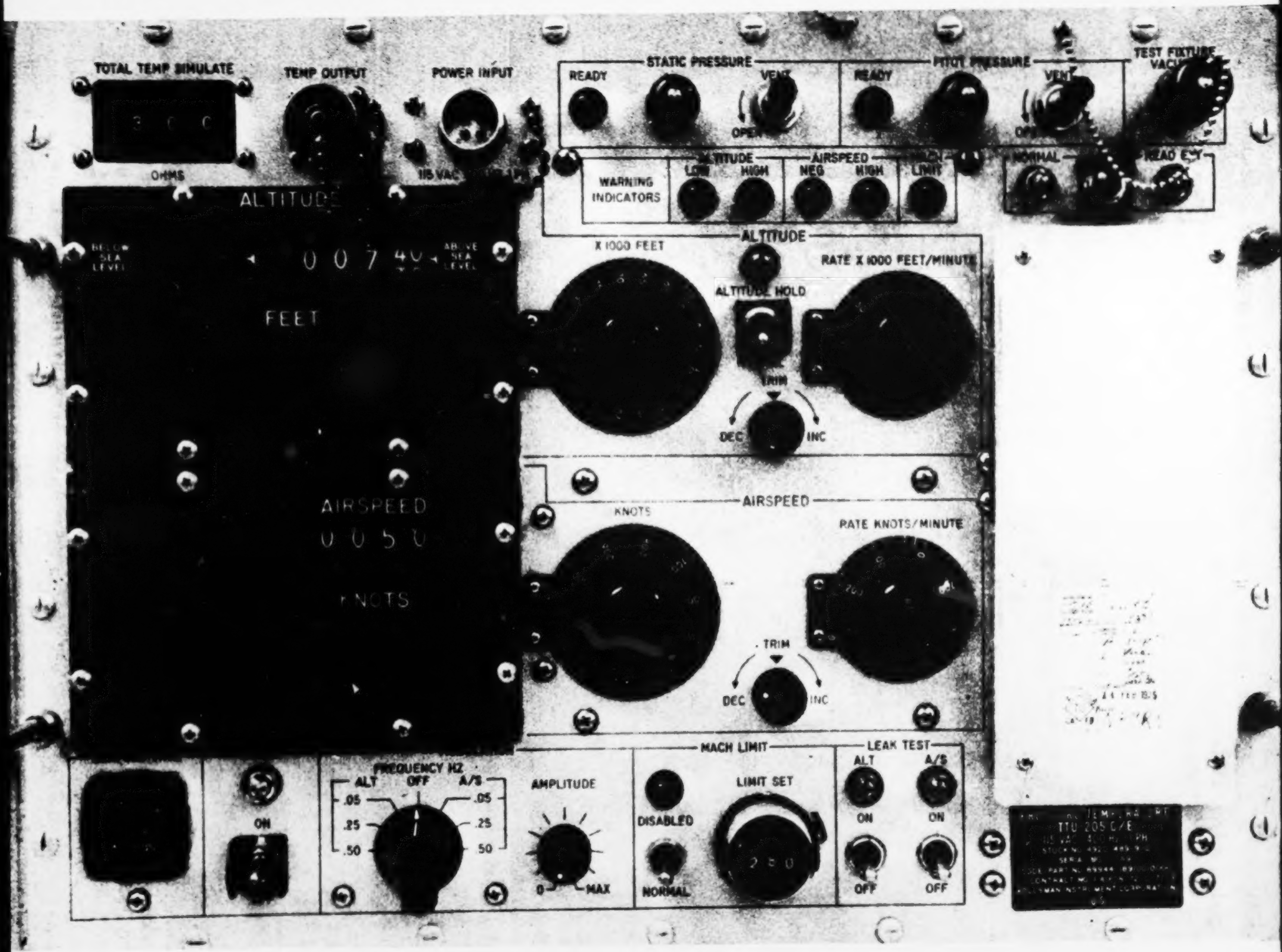

TOTAL TEMP SIMULATE
OHMS
TEMP OUTPUT
POWER INPUT
115 VAC
STATIC PRESSURE
READY
VENT
OPEN
PITOT PRESSURE
READY
VENT
OPEN
TEST FIXTURE VACUUM
WARNING INDICATORS
ALTITUDE
LOW
HIGH
AIRSPEED
NEG
HIGH
LIMIT
NORMAL
ALTITUDE
BELOW SEA LEVEL
ABOVE SEA LEVEL
FEET
ALTITUDE
X 1000 FEET
ALTITUDE HOLD
RATE X 1000 FEET/MINUTE
TRIM
DEC
INC
AIRSPEED
AIRSPEED
KNOTS
KNOTS
RATE KNOTS/MINUTE
TRIM
DEC
INC
ON
FREQUENCY HZ
ALT
OFF
A/S
.05
.25
.50
.05
.25
.50
AMPLITUDE
0
MAX
MACH LIMIT
DISABLED
NORMAL
LIMIT SET
LEAK TEST
ALT
A/S
ON
ON
OFF
OFF
TTU-205C/E

Figure 4-6. TTU-205C/E pneumatic systems test set.

pressure. In this case, no differential pressure is being sensed, and the EPR system is nulled (zero EPR).

Exercises (635):

1. What kind of power is supplied to the EPR system from the aircraft power source?

2. What is the purpose of the 26-volt tap on the primary of transformer T1 in the EPR transducer?

3. Which unit of the EPR transducer supplies the operating voltage to the capacitance bridge circuit?

635. Specify operational characteristics of the EPR system when the engines are operating.

System Operation. Now let's start the engine and cause an increase in exhaust pressure. The increase in exhaust pressure causes the exhaust pressure bellows to expand. As the bellows expand, the mechanical linkage moves the center plate of capacitor C5 in the direction shown by the arrow (bottom center) in figure 4-5.

For better understanding of the system operation, let's assign polarities to the applied voltage at the primary of transformer T1 in figure 4-5. As we assign the polarities, take a pencil and mark them on the units in the figure. For a given alternation of the input voltage, let's say that the polarity across the primary of T1 from top to bottom is negative (−) to positive (+). Transformer T1 is an in-phase transformer. This is indicated by the small dash line at the tops of the primary and secondary winding. There is no phase shift across the transformer. The polarities across the secondary windings are the same as across the primary (top to bottom − to +). Now follow the wires connected to the top and bottom of the bottom secondary winding of T1. Notice that they are connected to the outer plates of capacitor C5. You assign the same polarities to the plates of C5 as you did the secondary winding. The left plate is negative, and the right plate is positive for this alternation.

Follow the wire connected to the center tap of the bottom secondary winding. It is connected to ground at terminal 3. Therefore, the center tap of this transformer is always at the ground potential. The wire connected to the center plate of C5 is connected to a DC blocking capacitor at terminal 9. The signal-sensing circuit then is completed from the other plate of the DC blocking capacitor through the 1.0M and 2.4K resistors to ground at terminal 3. Now you should be able to see that when the center plate of C5 is centered it will be at ground potential; no current will flow in the signal-sensing circuit.

Remember that we had an increase in exhaust pressure that caused the center plate to move to the right. This was indicated by the arrow below C5. As the center plate moves closer to the outer plate, capacitance between the center plate and the right outer plate increases proportionately as the distance between plates decreases. Because of the increase in capacitance, the capacitive reactance(X_c) decreases, causing the voltage drop across the capacitor to decrease. The center plate then becomes positive (in relation to ground) by the amount the voltage drop decreased across the capacitor. Now the bridge circuit is unbalanced and current flows in the signal-sensing circuit.

The center plate of C5 is now positive in relation to ground. Current flows from the center tap of the bottom secondary winding to T1 through terminal 3. From terminal 3, the current flows through the 2.4K and 1.0M resistors. The capacitor at terminal 9 passes the effects of the signal to the center plate of C5 and to the opposite side of the bottom secondary winding of T1. With current flowing in this direction, a negative-to-positive voltage drop occurs across the 2.4K and 1.0M resistors. In this case, a positive signal is felt on the grid of amplifier tube 6112. Since amplifier tube 6112 is a 2-stage *class* A amplifier, the signal is amplified and shifted 180° by the second stage. The positive output signal is then coupled simultaneously to the grids of discriminator tube 5687.

Discriminator tube 5687 is biased at cutoff. It conducts only when a positive signal is present on the grids. However, only one side of the discriminator tube conducts. This depends upon which plate is positive in respect to the cathode. To determine the positive plate for this given alternation, recall the polarities that were assigned to the primary of T1. With a negative-to-positive polarity, from top to bottom, across the top secondary winding of T1, the bottom plate is positive. Therefore, the bottom half of the tube conducts on this alternation. When the tube conducts, current flows from: (1) the center tap of the transformer through the control phase winding of motor B3 to ground; (2) from ground to the bottom cathode of tube 5687; and (3) from the bottom plate of tube 5687 to the positive side of the transformer.

Now that current is flowing through the control phase winding of motor B3, the motor starts to run. The direction that it runs depends upon the phase relationship of the currents flowing in the control and fixed (reference) phases. For this particular alternation, the voltage of the control phase is in phase with the fixed phase. However, the current of the control phase is lagging that of the fixed phase by approximately 90°. Up to this point, we have traced the sensed signal through the servoloop for [redacted] one-half of the input voltage cycle. Now let's see what happens on the other half of the cycle.

On the other half cycle of the input voltage, all the polarities that we assigned to the units of the transducer will shift 180°. Now the polarities across the primary of T1, from top to bottom, will be positive (+) to negative (−). Take your pencil, a different color if possible, and assign these polarities to T1 in figure 4-5. At the same time, change the polarities across the secondaries of T1 and the plates of C5. The right outer plate of C5 is now negative in respect to ground, so current flows from the center plate through the 1.0M and 2.4K resistors to ground. With current flowing in this direction, a negative signal is felt on the grid of the first-stage amplifier. This is amplified and shifted 180° and coupled to the grid of the second stage. In the second stage, the signal is amplified and shifted 180°. The negative signal is coupled simultaneously to the grids of tube 5687. With a negative signal on the grids, the tube will not conduct even though the upper plate is positive. The negative signal on the grid causes the tube to go further into cutoff.

You should be able to see that the discriminator tube conducts only on the positive alternation of the sensed signal. Therefore, the output of the discriminator is in the form of pulsating DC. Consequently, the control phase of the motor receives a pulsating DC current. Notice in figure 4-5, a capacitor (C7) is connected in parallel with the control phase of the motor. Because of the natural operating characteristics of a coil and capacitor connected in parallel, an AC effect is felt across the control phase of the motor. This type of circuit provides constant torque and smoother operation of the motor. It is important that you know that the sensed signal that started the motor running is 180° out of phase with the system applied voltage.

The output shaft of motor B3 is mechanically connected to velocity generator G1, the outer plates of capacitor C5, and the rotors of synchros B1 and B2. As the motor drives, the mechanical linkage (1) turns the armature of generator G1, producing a damping feedback signal to the grid of amplifier tube 6112; (2) moves the outer plates of C5 until the center plate is centered, to cancel the input signal (balance the bridge circuit); and (3) positions the rotors of synchros B1 and B2. The increase in EPR is transferred from the transducer to the indicator by simple synchro circuits. The EPR indicator at this time shows the increase in EPR. Since the circuit from the transducer to the indicator is a simple synchro circuit, no explanation will be given at this time. You can review synchro circuits by referring to the chapter on synchronous indicating systems.

If a decrease in exhaust pressure occurs, the motor of the transducer runs in the opposite direction to position the rotors of the synchro units. Refer to figure 4-5.

Relate the following statements to our discussion of an increase in EPR. You should be able to follow the signal path through the circuit.

a. Assign the same polarities to transformer T1 as you did for each alternation of the input voltage for an increase in EPR signal.

b. The center plate of C5 moves in the opposite direction of the arrow shown under C5.

c. A decrease in EPR signal is 180° out of phase with an increase EPR signal.

d. A decrease in EPR signal is in phase with system applied voltage.

e. The amplifier operates the same as for an increased EPR signal.

f. The discriminator tube operates the same except that the upper half of the tube conducts when the grids are positive.

g. The motor drives in the opposite direction because the voltage of the control phase is 180° out of phase with fixed-phase voltage.

h. This voltage relationship effectively causes the circuit of the control phase to lead the current of the fixed-phase by approximately 90°.

Exercises (635):

In answering the following questions, assume that the engines are operating.

1. What factor actually causes the capacitance bridge circuit to become unbalanced?

2. What class of signal amplifier is used in the EPR transducer?

3. At what point is the discriminator tube of the EPR transducer biased?

4. What determines the direction of rotation of motor B3 in the EPR transducer?

5. What type of signal must be applied to the grids of the discriminator tube to cause the tube to conduct?

6. When is the signal sensed by C5 cancelled?

7. What is the purpose of velocity generator G1 in the EPR transducer?

8. What is the phase relationship between the voltage and current of the motor control phase in relation to the fixed phase when a decrease in EPR signal is sensed by C5?

636. Specify EPR system inspection and operational check procedures and component removal and replacement procedures.

Removal and Replacement of Components. Component removal and installation procedures for the EPR system were covered quite thoroughly in our discussion of instrument systems maintenance fundamentals. We will take a few minutes to try to tie them all together.

Removal. To gain access to the EPR transducer, you may have to get the crew chief to help you remove the engine cowling. The removal of *any* exterior panels on an aircraft should be recorded on the AFTO Form 781A under a red X

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symbol; therefore, you should insure that this is done immediately.

You can then proceed to cut the safety wire and disconnect the pneumatic tubing and electrical connections. Next, remove the four mounting screws in the base of the transducer and remove the transducer. Remove the fittings from the transducer and keep them for installation in the replacement transducer. If you do not immediately install a replacement item, plug or cap all open pneumatic lines and electrical connections, both on the removed transducer and on the aircraft or engine.

Installation. If you immediately install a replacement item, install a new, properly lubricated seal on each fitting. Install each fitting in its proper port on the transducer. (Different size fittings are used for Pt_2 and Pt_7 on some types of aircraft.) Install new mount screws and washers as required by the technical order. Also connect and torque the pneumatic lines as specified in the TO. Connect the electrical connector to the receptacle on the transducer and wire it with .020 steel safety wire. Use .032 steel safety wire to secure the pneumatic connections. Perform a leak check and an operational check of the system and do the necessary paper work; i.e., fill out the corrective action in the appropriate block of the AFTO Form 781A, complete your AFTO Form 349, and attach a properly documented AFTO Form 350 to the transducer you removed. Also help the crew chief reinstall the engine cowling. The general procedures at the beginning of this volume fully cover the removal and installation of the EPR indicator.

Inspection. When inspecting an EPR system, check all pneumatic tubing for tightness, proper installation, and indications of damage (such as chaffing) and leakage. All tubing and fittings must be steel. All connections on or close to the engine should be safetied. Check all electrical connections for tightness and safetying. Look for frayed or chaffing wires. Check the transducer and indicator for condition and security of mounting. While at the transducer, displace the moveable portion of the mounting rack in all directions and observe the coiled pneumatic tubing that is part of the mounting rack. There must be no interference between the tubes or between either tube and any part of the mounting rack. All of the required screws and washers must be installed. The rubber shock mounts must not be broken or cracked, and they must fully support the transducer.

Drains for the pneumatic tubing are located in the lowest part of the tubing. Open the drains and check for moisture. If there is any evidence of moisture in the lines, leave the drain open and disconnect the lines from the transducer. Using clean, dry, compressed air not over 50 psi, blow out the lines from the transducer end. Then hook the lines back up to the transducer, close the drain, and perform a leak check and operational check of the system.

Inspect the P_2 probe in the intake for security of mounting and obstructions. Also look for obstructions in the drain hole in the rear of the probe. This can be easily done by holding a flashlight behind the probe and looking through the probe. If you can see the light, it is OK. If you cannot see the light, clean the drain hole by pushing a piece of soft wire, such as copper, in through the front of the probe so as to dislodge the obstruction out the rear. If the front opening of the tube is obstructed, blow the lines out as described for moisture in the lines.

CAUTION: Before entering the intake to inspect or check the Pt_2 probe, remove your hat and empty your pockets to insure that nothing can be dropped and left in the intake.

To perform a leak check of the EPR lines, you must use a pneumatic systems tester, such as the TTU-205. The engine must be run (by run-qualified personnel) to perform an operational check of the system. Refer to the engine data in the aircraft flight manual to determine the correct EPR for the existing conditions. While the engine is running, observe the indicator for stable and correct indications. If the system proves to be faulty during the operational check, you must troubleshoot and repair the system.

Exercises (636):

1. Why do you displace the movable part of the transducer in all directions during an EPR system inspection?

2. What caution should you observe when inspecting a Pt_2 probe? Why?

3. How do you remove moisture or obstructions from EPR tubing?

4. What are you ~~checking for~~ checking for during an operational of the EPR system?

637. Given hypothetical troubles in the EPR system, state the indication to expect on the EPR indicator.

Troubleshooting. Table 4-1 lists some of the more common troubles that occur in the EPR system. You must realize that it is impossible to cover all the troubles that can occur in the EPR system. However, most troubles fall into the categories shown in the table. The probable causes are listed in order, from the most frequent to the least frequent cause of the trouble. Notice also that the suggested remedies, in all cases, pertain to repairing the troubles on the aircraft. It is not the intent of the Remedy column to identify repairs of the EPR system [illegible] components. Study the table and review figures 4-4 and 4-5 to become more familiar with the possible troubles.

As you can see, two pieces of test equipment are necessary if you are to troubleshoot the EPR system. A multimeter is necessary for checking system voltage and wiring. In addition to the multimeter, you must have some means of supplying pressure to the system tubing and transducer. This pressure source is necessary for locating

TABLE 4-1
TROUBLESHOOTING CHART FOR EPR SYSTEMS

Trouble	*Probable Cause*	*Remedy*
Indicator inoperative.	a. No power to transducer.	a. Correct faulty circuit protector. Repair wiring as necessary.
	b. No excitation voltage to indicator synchros.	b. Replace transducer. Repair wiring as necessary.
	c. No engine pressure to transducer.	c. Correct blocked or broken tubing.
	d. Faulty bellows, servoloop, or synchros.	d. Replace transducer.
	e. Faulty indicator.	e. Replace indicator.
Indicator hunts excessively.	a. Velocity generator or circuits defective.	a. Replace transducer.
	b. Indicator is actually reflecting transients of pressure.	b. Trouble is not in EPR system.
Indication varies erroneously with altitude.	a. Transducer case leaking.	a. Replace transducer.
	b. Loose or leaking tubing from engine to transducer. Most common.	b. Tighten or repair tubing.
	c. Transducer out of calibration.	c. Replace transducer.
Indicator reads abnormaly high or low (based on engine control setting).	a. Bellows or tubing leaking steadily.	a. Replace transducer. Repair tubing.
	b. Amplifier defective.	b. Replace transducer.
	c. Transducer out of calibration.	c. Replace transducer.
Indicator pointer runs continuously in one direction.	a. Faulty discriminator.	a. Replace transducer.
	b. Sensing capacitor (C-5) maladjusted.	b. Replace transducer.

leaks in the tubing and supplying known pressures to the transducer. With these thoughts in mind, take a look at a tester used for this purpose.

Exercises (637):

1. Referring to figure 4-5, what is the indication on an EPR indicator if the top wire at terminal 10 is open?

2. Referring to figure 4-5, what is the indication on an EPR indicator if the wire connected to pin 1 of tube JCN5687 is open?

3. Referring to figure 4-5, what is the indication on an EPR indicator if the wire connected between pin E of J1 and pin A of J2 is open?

638. Specify the purpose and operational characteristics of the TTU-205 pressure temperature test.

Test Equipment(TTU-205 Subassemblies). Although a manually operated pneumatic test set (or pressure ratio tester) was designed to check the EPR system, improvements to the TTU-205 pressure- temperature test set make it much more accurate and it reliable, and is preferred for checking EPR systems. For that reason, we will discuss the TTU-205 only. If your shop is still using the pressure ratio tester, you will learn about it through OJT.

The TTU-205 pressure-temperature test set is shown in figure 4-6. This test set is used to provide regulated pitot and static pressures for evaluating performance of aircraft pneumatic instruments (EPR), air data systems, flight instruments, and other equipment. It is used to do operational checks, calibration tests, and leak checks.

All of the controls, indications, switches, electrical connectors, and pneumatic connectors are mounted on the front panel of the test set. All of the other subassemblies are mounted on the under side of the control panel inside the test set. The test set simulated airspeed and altitude information is read out directly on the display on the front panel as knots for airspeed and feet for altitude; therefore, for EPR systems, you must refer to the technical order to convert these readings to units of EPR.

The TTU-205 test set requires 115-volt, 400 Hz, single-phase power for operation. The test set is approximately 25 inches long, 19 inches wide, and 14 inches high and has a total volume of 3 cubic feet. It weighs 97 pounds; therefore, you should get help if you must carry it.

The test set simulates altitude through a range of −1,500 feet to 80,000 feet with a tolerance of ± percent. This altitude range is equal to approximately 31.5 to 0.80 inches of Hg. The simulated airspeed range is 50 to 1,000 knots with a tolerance of ± 1.5 knots. This airspeed range is equal to approximately 0.12 to 73.5 inches of Hg.

In order to check an EPR system for accuracy, the test set must have a minimum range of 30.0 to 7.0 Hg altitude (−74 ft to 35,140 ft) and 10.5 to 90 Hg airspeed (264.8 kts to 917.4 kts). From this, you can see that the TTU-205 is well suited for the EPR system.

Exercises (638):

1. What is the TTU-205 test set used for?

2. The controls, indicators, switches, electrical connectors, and pneumatic connectors are mounted on the ________ ________ of the test set.

3. The airspeed and altitude information from the test set is displayed directly on the _______ _______ of the test set.

4. What equipment does the test set perform overall system checks on?

5. The power requirements for the TTU-205 test set is ________ ________ volts, ________ power.

6. The size of the test set is ________ cubic feet by volume and it weighs ________ pounds.

7. The altitude range of the TTU-205 test set is ________ feet to ________ feet with a tolerance of ________. This altitude range is equal to approximately ________ to 0.80 inches of Hg.

8. The airspeed range of the TTU-205 test set is ________ to ________ knots with a tolerance of ± ________. This airspeed range is equal to approximately ________ to ________ inches of Hg.

639. Identify the functions and descriptions of controls and indicators of the TTU-205 test set assemblies.

TTY-205 Subassemblies. The purpose of this discussion is to explain the usage of the subassemblies and controls of the TTU-205 test set. This will give you a broad understanding of how the test set is used. Now refer to the upper portion of figure 4-6 as we begin our discussion.

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The TOTAL TEMP SIMULATE unit is a decade resistor with a range of 30.0 to 129.9 ohms in 0.1-ohm increments. It simulates temperature by using different resistance values. The TEMP OUTPUT receptacle provides a method of transferring the simulated temperature to the unit under test. We will cover this function in depth when we get to the air data computer system. The POWER INPUT connector provides connection for external power to the test set.

The STATIC PRESSURE READY indicator lamp illuminates when static pressure output of the test set is under control of the front panel controls. The STATIC PRESSURE connector connects the Ps output to the unit under test. The manual STATIC PRESSURE VENT valve provides a means of venting the static pressure line to the atmosphere. The PITOT PRESSURE READY INDICATOR lamp illuminates when the pitot pressure output of the test set is under control of the front panel controls. The pitot pressure coupling connects the Pt output to the unit under test. The manual PITOT PRESSURE VENT valve provides a method of bleeding Pt pressure to the atmosphere. The TEST FIXTURE VACUUM coupling is a means of connecting the vacuum output to a flush static test fixture.

Now let's look at the warning indicators just below the units just discussed. The first one is the ALTITUDE LOW indicator lamp. It illuminates to indicate when the altitude (Ps pressure) is approaching 32 inches of Hg (−1,870 feet). The ALTITUDE HIGH indicator lamp illuminates to indicate that static pressure is approaching 0.7 inches of Hg (approximately 83,000 feet). The AIRSPEED NEG indicator lamp illuminates when the static pressure has exceeded total pressure. The AIRSPEED HIGH indicator lamp illuminates when the airspeed (Pt pressure) is approaching 75 inches of Hg (approximately 1,008 knots). The MACH LIMIT indicator lamp illuminates to indicate that the airspeed is being limited so that the Mach will not exceed the Mach setting.

The NORMAL lamp illuminates when the test set is in the generating mode. The READ EXT lamp illuminates when the test set is operating in the indicating mode. The NORMAL/READ EXT switch (between the two indicator lamps) is a double-pole, double-throw switch that is a method of switching operation of the test set from generating to indicating pressures.

Now let's move down to the center portion of the control panel. The first unit is the ALTITUDE × 1,000 FEET variable resistor. This unit is used to make a coarse setting to the desired altitude. The ALTITUDE RATE × 1,000 FT/MIN variable resistor sets the maximum altitude rate between the altitude settings. The ALTITUDE HOLD/NORMAL switch is a double-pole, double-throw toggle switch that enables the operator to lock in and hold a specific altitude for greater than normal stability. The ALTITUDE HOLD lamp illuminates when the ALTITUDE HOLD/NORMAL switch is in the ALTITUDE HOLD position. The ALTITUDE TRIM variable resistor provides fine adjustment of altitude (ps pressure).

Now look at the ALTITUDE FEET counter just to the left of the units just discussed. This unit is a counter-type module that displays the simulated altitude output of the test set in a digital readout. Just below the ALTITUDE FEET counter is the AIRSPEED KNOTS counter. This unit is also a counter-type module. It displays the simulated airspeed output of the test set in a digital readout.

Now let's move back to the right and see what the airspeed variable resistors do. The AIRSPEED KNOTS variable resistor allows for coarse setting of the desired simulated airspeed. The AIRSPEED RATE KNOTS/MINUTE variable resistor is used to set the maximum simulated airspeed rate between the airspeed settings. The AIRSPEED TRIM variable resistor permits a fine adjustment of the test set simulated airspeed indication.

Refer now to the controls and indicators at the bottom of the control panel. The LEAK TEST A/S indicator lamp illuminates when the A/S ON/OFF switch is actuated. The LEAK TEST A/S ON/OFF switch is a double-pole, double-throw toggle switch. It is spring-loaded to the OFF position. When the switch is in the ON position, it isolates the unit under test from the Pt source and enables the operator to determine the airspeed leak rate. The LEAK TEST ALT indicator lamp illuminates when the ALT ON/OFF switch is actuated. The LEAK TEST ALT ON/OFF switch is also a double pole, double-throw switch and is spring-loaded to the OFF position. When the switch is in the ON position, it isolates the unit under test from the Ps source and enables the operator to determine the altitude leak rate.

The MACH LIMIT SET is a variable resistor that enables the operator to set a limit on Mach numbers so that the simulated airspeed and altitude combinations do not exceed the safe Mach limits of the unit under test. The MACH LIMIT NORMAL-DISABLE switch is a single-pole, double-throw switch that allows the operator to bypass the MACH LIMIT SET. The MACH LIMIT indicator lamp illuminates when the switch is in the DISABLED position. The MODULATION AMPLITUDE variable resistor permits adjustment of the modulation amplitude for the Ps or Pt output. The MODULATION FREQUENCY HZ switch enables the operator to set the frequency for airspeed or altitude variations.

The POWER ON/OFF switch switches the test set on or off. The lamp just above the switch illuminates when the switch is moved to the ON position. The ELAPSED TIME meter is a time-totalizing meter that records the total power-on time of the test set.

This completes our discussion of the TTU−205 test set. Now let's see what you have learned by completing the following exercises.

Exercises (639):

1. Match the controls/indicators of the TTU−205 test set listed in column A with their functions/descriptions listed in column B. Write the correct letter in the space provided. Some functions/descriptions may be used more than once and some may not be used.

Column A

____ (1) Power input.
____ (2) Static pressure ready indicator lamp.
____ (3) Static pressure connector.

Column B

a. Illuminates when the altitude hold/normal switch is in the altitude hold position.
b. Provides a means of switching operation of the test set from

Column A

_____ (4) Altitude low indicator lamp.
_____ (5) Static pressure vent.
_____ (6) Altitude high indicator lamp.
_____ (7) Airspeed negative indicator lamp.
_____ (8) Pitot pressure ready indicator lamp.
_____ (9) Airspeed high indicator lamp.
_____ (10) Pitot pressure coupling.
_____ (11) MACH LIMIT indicator lamp.
_____ (12) Pitot pressure vent.
_____ (13) Test fixture vacuum coupling.
_____ (14) READ EXT lamp.
_____ (15) NORMAL/READ EXT switch.
_____ (16) Normal lamp.
_____ (17) Altitude hold lamp.
_____ (18) Alitude rate × 1,000 feet/minute resistor.
_____ (19) Pump cover.

Column B

generating to indicating pressures.
c. Provides a means of holding the Ps adapter to the statis ports.
d. Illuminates when the airspeed is being limited.
e. Illuminates when the pitot pressure output is under control of the front panel controls.
f. Provides a means of venting static pressure.
g. Illuminates when the statis pressure output is under control of the front panel controls.
h. Simulates temperature by using different resistances.
i. Covers the pump air intake and fan exhaust.
j. Illuminates when the test set is in the indicating mode.
k. Is a double-pole, double-throw switch.
l. Illuminates when the test set is operating in the indicating mode.
m. Illuminates when Pt pressure is approaching 32 inches Hg.
n. Illuminates when Ps pressure is approaching 32 inches Hz.
o. Provides connection for external power to the test set.
p. Sets the maximum altitude rate between altitude settings.
q. Is a sigle-pole, double-throw switch.
r. Provides a means of bleeding Pt pressure.
s. Illuminates when Ps has exceeded Pt.
t. Illuminates when Ps pressure is approaching 0.7 inches Hg.
u. Illuminates when the altitude hold/normal switch is in the NORMAL position.
v. Illuminates when the test set is in the generating mode.
w. Connects the Pt output to the unit under test.
x. Connects the Ps output to the unit under test.

2. Match the controls/indicators of the TTU–205 test set listed in column A with their functions/descriptions listed in column B. Write the correct letter in the space provided. Some functions/descriptions may be used more than once and some may not be used.

Column A

_____ (1) Altitude hold/normal switch.
_____ (2) A/S rate knots/minute resistor.
_____ (3) Lead test A/S indicator lamp.
_____ (4) Lead test A/S on/off switch.
_____ (5) LEAK TEST ALT indicator lamp.
_____ (6) LEAD TST AT on/off switch.
_____ (7) Airspeed trim resistor.
_____ (8) MACH LIMIT, limit set resistor.
_____ (9) ALTITUDE TRIM resistor.
_____ (10) MACH LIMIT normal-disable switch.
_____ (11) Mach limit indicator lamp.
_____ (12) Modulation amplitude resistor.
_____ (13) A/S knots resistor.
_____ (14) Frequency modulation switch.
_____ (15 Power on/off circuit breaker.
_____ (16) Power on/off indicator lamp.
_____ (17) Elapsed time meter.
_____ (18) Counter-type airspeed indicator.
_____ (19) Coarse altitude resistor.
_____ (20) Counter-type altitude indicator.

Column B

a. Displays the altitude output of the test set.
b. Displays the airspeed output of the test set.
c. Provides the means for turning power on and off on the test set.
d. Enables setting of the frequency of modulation for A/S and altitude.
e. Illuminates when the mach limit switch is in the disabled position.
f. Permits the operator to set a limit on MACH number.
g. Provides the means for the operator to determine altitude leak rate.
h. Illuminates when ALT LEAK TEST switch is actuated.
i. When on, isolates the unit under test from the Pt source.
j. Sets the maximum airspeed rate between airspeed settings.
k. Its display is a digital readout.
l. Illuminates when external power is applid to the test set.
m. Permits adjustments of the modulating amplitude for the Ps or Pt outout.
n. Permits fine adjustment of the airspeed indicator.
o. When on, isolates the unit under test from the Ps source.
p. Allows the altitude to be locked in for greater stability.
q. Is a single-pole, single-throw switch.
r. Monitors total power-on time of the test set.
s. Permits coarse setting of the desired airspeed.
t. Permits fine adjustment of the altitude indication.
u. Provides the means for the operator to determine airspeed leak rate.
v. Is a doble-pole, double-throw switch.
w. Allows for coarse setting of the desired altitude.
x. Allows the operator to bypass the MACH limit set resistor.
y. Illuminates when the A/S leak switch is actuated.
z. Sets the minimum airspeed rate between airspeed settings.

640. Specify EPR system checkout procedures using the TTU–205 Test Set.

Checking EPR Systems. You must check the engine pressure ratio system tubing and transducer for leaks before performing an operational or accuracy check. This is a simple procedure which you will easily learn through OJT. We will go through an accuracy check so that you will understand the test equipment operation. This will give you the basic knowledge to permit you to readily learn other procedures.

The first step is to visually inspect the system and repair any discrepancies noted. Place your test set (TTU–205) on a level surface (± 10°), and connect the power cable to the test set and a power source. Close the STATIC and PITOT VENT valves (fully CW). Set the ALTITUDE × 1,000 FEET control to sea level, and the AIRSPEED KNOTS control to 150. Set the ALTITUDE and AIRSPEED TRIM controls to the center of their 5-turn range. Set the

ALTITUDE RATE × 1,000 FEET/MINUTE to 10,000, and the AIRSPEED RATE KNOTS/MINUTE to 200 knots per minute. Set the MACH LIMIT switch to normal, and the LIMIT SET control to 1.50. Make sure that the MODULATION FREQUENCY HZ switch is set at OFF and that the MODULATION AMPLITUDE is at zero (0). The ALTITUDE and AIRSPEED LEAK TEST switches should be to OFF with the ALTITUDE HDLD switch at NORMAL. Now you can put the power switch to ON. When the two green READY lights illuminate, wait 10 minutes for the test set to warm up before proceeding.

After your test set has warmed up for the minimum 10 minutes, cycle the altitude, twice, between sea level and 75,000 feet. Then cycle the airspeed, twice, between 100 knots and 950 knots. The warm-up period and cycling process activates the sea level microswitch, flexes the internal diaphragms, lubricates moving parts, and insures that the test set is ready for use. Now you are ready to connect the test set to the system to be checked.

Insure that the ALTITUDE is at the altitude of your location (ambient barometric pressure) and that the AIRSPEED is at 50 knots. Connect the static pressure hose to the red coupling on the test set and the pitot pressure hose to the blue coupling.

Disconnect the Pt_2 probe, and connect the loose end of the static pressure hose to the tubing going to the transducer. This connection is made as close to the inlet pressure probe as possible so that as much of the tubing as possible may be checked.

Connect the loose end of the pitot pressure hose of the tester to the exhaust pressure (Pt_7) line on the engine. Make this connection as close as possible to the manifold for the exhaust pressure probes.

CAUTION: Never permit exhaust (Pt_7) pressures to be less than the inlet (Pt_2) pressures. Do not drive the transducer above a pressure ratio of 3.5.

Using the ALTITUDE × 1,000 FEET control, set in −74 feet and allow the counter to stabilize at −74 feet. Place the ALTITUDE HOLD/NORMAL switch to ALTITUDE HOLD.

Using the AIRSPEED KNOTS control, set in each of the six test points shown in the applicable TO (they should be approximately the same as given in table 4-2) for −74 feet (or 30.0 Hg) and check the pressure ratio gage for readings that should be within the specified tolerance. Tap the pressure ratio gage lightly on the case to eliminate friction error before each reading. Never tap any indicator directly on the cover glass; it is easily broken. During pressure changes, the pointer of the EPR gage should move smoothly and not lag behind the test set.

If all checks at −74 feet are within the required tolerance, set the AIRSPEED to the first test point at 35,140 feet. In table 4-2, that is 264.8 knots.

Return the ALTITUDE HOLD switch to NORMAL, and set the ALTITUDE to 35,140 feet. After the counter stabilizes, put the ALTITUDE HOLD/NORMAL switch back to ALTITUDE HOLD.

Using the AIRSPEED KNDTS control, again at a very slow rate, adjust the tester to each of the test points given for the altitude of 35,140 feet. Check for proper EPR gage readings after tapping the gage lightly before each reading.

Set the AIRSPEED KNOTS control to 50, return the ALTITUDE HOLD/NORMAL switch to normal, and adjust the ALTITUDE × 1,000 FEET control to local field elevation. Allow the counters to stabilize before removing the Ps and Pt hoses. Finally, place the POWER SWITCH to OFF and open the Pt and Ps equalizer (VENT) valves.

Reconnect and safety the inlet and exhaust pressure tubing and perform an operational check of the EPR system on the next required engine run to verify that the tubing was reconnected properly and that no problem exists with the Pt_7 probes or the engine.

If defects or out-of-tolerance conditions exist, you must troubleshoot and repair the system. If everything checked was good, document your actions in the appropriate AFTO Form 781A block and complete your AFTO Form 349.

Lightly close the Pt and Ps VENT valves on the tester. Put dust plugs in the hoses, and return the hoses and power cord to the storage area in the lid of the tester. Exercise care when putting the lid on the tester; it will only fit one way. Improper installation could damage the VENT valves.

Exercises (640):

1. What is the first step in checking an EPR system?

2. Before you turn on the TTU-205, what position must the STATIC VENT valve be in?

3. What is the range of the altitude and airspeed trim controls?

4. Prior to turning on the TTU-205 test set, where should you set the airspeed and altitude trim controls?

5. What is the purpose of the warm-up period and cycling process of the TTU-205?

6. State when the TTU-205 test set is connected to the EPR system.

7. State how the TTU-205 test set is connected to the EPR system.

TABLE 4–2
ALTITUDE, AIRSPEED AND HG CONVERSIONS TO UNIGS OF EPR

Engine Inlet Pressure (Pt2)		Engine Exhaust Pressure (Pt7)		Pressure Ratio Reading
Altitude-feet	Hg	Airspeed-knots	Hg	(+0.025 units)
−74	30	518.5	45	1.50
−74	30	692.5	60	2.00
−74	30	744.8	66	2.20
−74	30	814.9	75	2.50
−74	30	836.5	78	2.60
−74	30	917.4	90	3.00
35,140	7	264.8	10.5	1.50
35,140	7	367.7	14.0	2.00
35,140	7	432.1	17.0	2.43
35,140	7	503.3	21.0	3.00

641. State how to insure the accuracy of an aircraft EPR indicator, and name the types of tests on an EPR transducer in the field.

Bench Check and Calibration. Bench checking and calibration of different EPR systems requires sensitive test equipment. We will not cover the adjustment procedures in this text. Understanding of such aspects can best be achieved by performance on the job. However, giving you an idea of the setup and bench check procedures should be helpful. You will find that the TOs for the different transducers have detailed information about the bench check and the adjustment procedures.

To do a complete bench check, it is necessary to have temperature and pressure standards and a controllable vacuum-pressure source. These may be built-in to specialized test equipment such as the universal transducer test stand. This type of equipment is normally available only to selected depot facilities because the environment where it is used must be strictly controlled. Room temperature must be kept within certain parameters such as not lower than 70°F and not higher than 74°F. The delicate fit of the parts inside of EPR system components, as well as other instruments, can be upset by minute particles of dust; therefore, the facilities where these components are repaired must be kept dust free. Needless to say, better than normal housekeeping must be enforced. For these reasons, you will probably never repair, calibrate, or adjust an EPR transducer or indicator, so we will not cover the temperature compensation, amplifier, and null-current tests. Neither will we cover the difference data sheets which specify the differences in different models of each type of transducer or indicator.

However, some field shops have built mockups of EPR systems that they use to bench check or functionally check the components prior to installation in the aircraft. In this type of setup, an aircraft EPR gage is calibrated as accurately as possible by the local precision measurement equipment laboratory (PMEL) and used as a standard for reading the output of the EPR transducer. The TTU–205 is used to supply the required pressures to operate the transducer. With this type of equipment, you must use the aircraft technical manual to perform the leak check and scale error test. In order to determine allowable tolerances for position error tests, friction error tests, and ohms-short (resistance) tests, you must refer to the overhaul manuals.

The accuracy of the different types of indicators can be checked with a synchro field tester or a precision synchro tester. Because they are hermetically sealed, the EPR indicators cannot be repaired in the field shops. Regardless of which component of the system you want to check, it is necessary that you become familiar with the technical order pertaining to that component.

Exercises (641):

1. If an aircraft EPR indicator is used as a standard for checking EPR transducers, what action must be taken to insure the accuracy of the indicator?

2. What type(s) of test(s) can be performed during a bench check of an EPR transducer in a field shop using the procedures given in the aircraft technical manual?

CHAPTER 5

Tachometers and Temperature Indicating Systems

SINCE MAN developed flying machines, a means of controlling the speed of the engine has been necessary. Remember Snoopy and his Sopwith Camel? Engine speed on the Sopwith Camel was controlled by a device known as a kill button. The engine on this aircraft has only one speed, full power. In order to control it, Snoopy had to press this button and actually kill the engine momentarily. This would slow the engine down for speed changes and ground operation.

We're not really sure about Snoopy's Sopwith Camel, but most aircraft systems are affected by temperature. For example, the effective operation of an engine is dependent upon the temperature of the free air (air surrounding the aircraft), the carburetor air (air entering the carburetor of a reciprocating engine), the temperature of the oil, and—in some cases—the temperature of the fuel. The temperature of the cylinder head of a reciprocating engine exhaust of a jet engine is also most important. All of these temperatures must be kept within prescribed ranges for efficient operation of the engines and safe operation of the aircraft. The pilot must know the ambient (free) air temperature in order to compute takeoff, landing, and navigational information.

In this chapter, we will discuss the necessity and uses of devices that measure and control engine speed and temperature.

5-1. Tachometers

Fuel control devices, operated by the pilot, were developed, after the days of the Sopwith Camel, to control engine speed. The pilot then needed an instrument to show how fast the engine was turning. The aircraft tachometer was developed for this purpose. The tachometer is a counting device that counts the revolutions of the engine main shaft for a given period of time. This gives us a measurement of engine speed in revolutions per minute (rpm). By knowing the rpm of the engine, the pilot can control the power output of that engine. At the same time, he or she can select the best power setting for maximum fuel economy.

In the early days of aviation, when reciprocating, piston-driven engines powered the aircraft, actual rpm of the engine was displayed in the cockpit. The rpm indicating system used in today's jet propelled aircraft gives engine speed in a percentage of a maximum rated rpm. The engine speed at a given rated power is determined after the engine has been assembled. This system gives the operator (pilot, jet engine mechanic, or ground crew operator) an indication of how fast the N2 compressor is turning. This indication of rpm is a percentage of the maximum rpm normally permitted. The N2 compressor of each engine drives a tachometer generator that produces an electrical signal that is in proportion to the speed of the N2 compressor.

The system that we shall concentrate on has several features that make it more desirable than other types of tachometer systems. It is a frequency-sensitive system that provides very accurate indications regardless of voltage variations caused by temperature changes. Noticeably absent from the system are such elements as brushes, commutators, or sliprings that, in other systems, were sources of faulty indications and radio interference. However, the components of these tachometer systems sometimes fail. In doing so, they cause maintenance problems. With these thoughts in mind, let's take a look at the tachometer systems components.

642. Specify the operational characteristics of the tachometer generator and indicator components.

Generators. The tachometer generator is mounted on the oil pump and accessory housing. It is turned through gears by the high speed (N2) compressor of the engine. It consists of a stationary, three-phase, wye (Y) winding and a permanent magnet rotor. One feature is the small, compact size of this unit. It is only a few inches in diameter and length.

The generator drive shaft, which is an extension of the rotor shaft, protrudes through the mounting base at the bottom of the generator. A tachometer drive unit is a part of the accessory section of the engine. On reciprocating engines, it is connected to the engine drive shaft by a gear train so that it turns the rotor of the generator at a speed proportionate to that of the engine crankshaft. That is once for every two revolutions of the crankshaft.

On jet engines or turbo prop engines, the tachometer drive is connected to the high speed (N2) compressor by a gear train. This causes the rotor of the generator to turn at a speed proportionate to that of the compressor. Since the speed of the turbine shaft in jet engines varies from engine to engine, the gear ratio also varies for different engines. However, the general rule is that the generator turns at one-fourth of the engine shaft speed.

The generator rotor will have either two or four magnetic poles, depending upon the type of engine it is to be used on. The two-pole type is normally used on jet engines. The two-pole generator has only two pins in the electrical connector because one phase of the signal is grounded in the generator. The two-pole and four-pole rotors are similar in construction and in appearance. The only difference is in the way they are magnetized. The two-pole rotor is magnetized so that the effective magnetic poles are 180° apart. This method of magnetizing causes the magnetic lines of flux to concentrate around the two-pole rotor, as shown by the dotted lines in figure 5-1. However, the four-pole rotor is magnetized so that the effective poles are every 90° around the rotor. The concentration of the magnetic lines of flux around the four-pole rotor is also shown in figure 5-1. The generators that have two poles produce one cycle of voltage for each revolution of the rotor. Those having four poles develop two cycles of voltage for each revolution. The four-pole type is used on reciprocating engines.

The stator of the generator has a steel ring that has a low reluctance, laminated, metal core. Around this core is placed a three-phase winding that is insulated from the core. The rotor turns within the stator and produces a three-phase alternating current (AC). The frequency of this current depends upon the number of magnetic poles of the rotor and the speed that the rotor rotates within the stator windings.

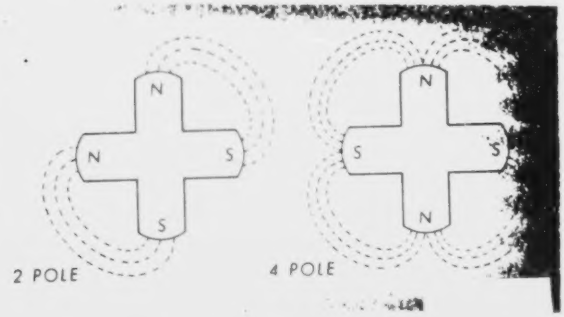


Figure 5–1. Magnetic poles in tachometer generators.

Indicators. The indicators used in these motor-generator tachometer systems are composed of two major assemblies—a three-phase motor and a magnetic drag assembly. Two different types of construction are used in the making of the indicators. The first type has a three-phase, induction type motor. The motor has A three-phase, Y-wound stator and a squirrel-cage rotor. The dial of this indicator is graduated in percent of rpm, rather than in actual rpm. The indicators used on jet engine aircraft are calibrated in percent of normal engine rpm. This is because jet engine rpm is normally three to six times greater than that of a reciprocating engine. Consequently, for the sake of simplicity, the dial is calibrated in percent of rpm instead of actual rpm.

Figure 5-2 is an exploded view of an induction-motor type of indicator. It shows the motor (H and G) and the magnetic drag unit (F). The drag unit is a four-pole magnet surrounded by a magnetic shield. A copper cup (E) fits over this arrangement. The sides of the cup fit between the magnet and the magnetic shield. The copper cup, or drum (E), is connected, directly or through gears, to the pointer shaft. The center ends of the hairsprings (C) are fastened to the pointer shaft (D). The other ends are anchored to the frame of the instrument. They allow the magnetic drag unit to move the pointers (A and B) only within the limits of the dial. Then they return the pointers to zero after the tachometer generator ceases to produce a signal.

The second type of construction employs a three-phase synchronous motor. The actual rpm of the engine is indicated on the dial. These indicators may have two pointers for dual-engine indications. The scale range is usually from 0 to 4,500 rpm or from 0 to 110 percent of rpm. Aside from this difference, however, the function of the indicator remains the same. The hysteresis disc in the motor is mounted directly on the motor shaft. The permanent magnet directly behind it is free to revolve on the motor shaft, although it is connected to the shaft by a

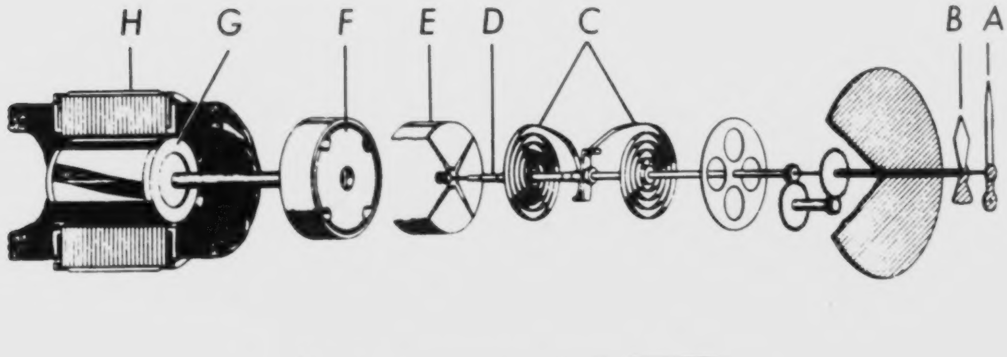


Figure 5–2. Breakdown of a tachometer indicator.

hairspring. The magnet rotates within the stator coils. With this arrangement, the magnet is able to make almost one complete revolution before its motion, through the spring, is transmitted to the shaft. The next section contains the magnetic drag assembly that contains two plates, each having six small magnets. These plates are bolted together so that the magnets face each other across a small airgap, their opposite poles facing each other. An aluminum drag disc is positioned in the airgap between the magnets. It is connected to the pointer shaft either directly or by means of a gear. A coil spring restrains the turning of the disc, and the pointer moves within the limits of the dial. All of the parts that have been described above are inclosed in the case with an electrical connector at the rear.

The indicators just described are merely examples of the various types used. The percentage-calibrated dials are not confined to use with the induction-motor-type indicators; nor are all those calibrated in rpm used only with the synchronous type. The type of indicator depends upon the manufacturer.

Exercises (642):

1. State where the tachometer generator is usually mounted on the aircraft.

2. What type of stator is used in the tachometer generator?

3. What type of rotor is used in the tachometer generator?

4. What is the rotor of the tachometer generator turned by?

5. What is one main difference between the two-pole and the four-pole rotor?

6. One revolution of a two-pole rotor will produce ________ cycle(s) of voltage.

7. The type of voltage produced by a tachometer generator is ________ ________ ________ .

8. Why are the tachometer indicators used on jet aircraft calibrated to show percentage of rmp instead of actual rmp?

9. The two basic types of tachometer indicator motors are ________ ________ and ________ ________ .

10. What is the main difference between the two basic types of tachometer indicators?

643. State the factors that determine the operation of the tachometer system and give the purpose of components that comprise the tachometer system.

Operation. Although the indicators used in a tachometer system have different types of motors, they operate in the same manner except for one slight difference. In the induction-motor-type indicator, such as the one in figure 5-3, the generator is driven directly from the accessory section of the engine. As it turns, 3-phase voltage is produced. The amount and frequency of the voltage depend entirely upon the speed at which the generator shaft is rotating. This output of the generator is carried to the stator of the induction motor. The lines of force from the rotating field cut across the squirrel-cage rotor. This induces voltage and currents within it. These currents produce a magnetic field within the rotor and cause it to turn at the same rpm as the generator. Since the squirrel-cage rotor is connected to the magnet in the magnetic drag assembly, that magnet will also turn at the same rpm as the generator.

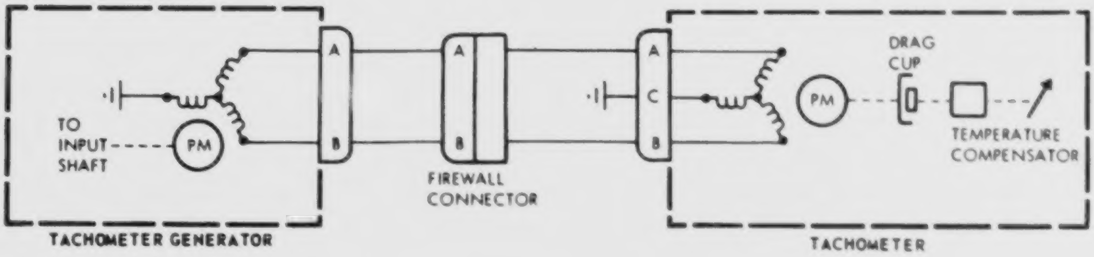


Figure 5-3. Schematic of a tachometer system.

As the magnet rotates, its lines of force cut across the copper drum. This causes currents to be induced into the drum, thus producing a magnetic field. The interaction between the field of the permanent magnet and that produced in the drum causes a torque to be applied to the drum. Were it not for the coiled spring fastened to the pointer shaft, the copper drum would spin along with the rotating magnet. However, the spring restrains the drum movement. The drum moves only until the opposition of the spring equals the torque produced by the magnetic fields.

When the rpm of the aircraft engine increases, the frequency output of the generator increases. This, in turn, increases the speed of the induction motor. This last increase causes the magnet in the drag assembly to rotate faster. This now causes the drum to move until the torque is balanced by the tension of the coil spring. These same events take place as engine speed decreases, but in reverse order. The purpose of the drag unit, then, is to change the rpm of the indicator motor into pointer deflection. Since the rpm of the indicator motor depends upon the frequency of the generator and not upon the voltage output, the system is said to be frequency sensitive.

The synchronous-motor-type indicator is almost identical to the induction-motor-type except for the type of motor used. The rotor of the synchronous motor is made up of three parts, a permanent magnet and a hysteresis disc mounted on a common shaft. The purpose of the permanent magnet is to provide starting and running torque for the motor during low frequencies (rpm). The permanent magnet rotor is mounted loosely on the shaft. At the end of its free rotation, it engages a spring through which it transmits a torque to the rotor shaft. This allows the rotor to synchronize with the rotating field before the shaft picks up any load.

The purpose of the hysteresis disc is to provide starting torque at high frequencies (rpm) when the magnitude of flux is high. But the permanent magnet, by itself, will not pull the rotor into synchronization. At the higher generator speeds, the hysteresis disc moves the rotor up to near synchronization. Then the permanent magnet pulls the rotor into exact synchronization. The hysteresis disc also aids in stabilizing the rotor during quick frequency (rpm) changes and prevents pointer oscillation.

The construction of the magnetic drag assembly for the synchronous indicator differs from that of the induction-motor indicator. However, their operation is identical.

Exercises (643):

1. What determines the frequency and amount of voltage output of a tachometer generator?

2. What is the purpose of the coil spring attached to the pointer shaft of a tachometer indicator?

3. State the factor that determines the speed of the motor in a tachometer indicator.

4. State why the permanent magnet rotor of the synchronous motor tachometer indicator is mounted loosely on the rotor shaft.

5. Give the name of the component that stabilizes the pointer of a synchronous motor tachometer indicator during quick rpm changes of the engine.

644. Specify inspection and operational check procedures of the tachometer indicating system and identify the probable causes of given malfunction indications.

Inspection, Operational Check, and Troubleshooting. When you are required to inspect a tachometer system, you generally check the same items that you check when inspecting the instrument systems we have discussed this far. You check the indicator for security of mounting, condition and proper placement of range markings, and general overall condition. You check the generator for security of mounting and general overall condition. You also check the electrical wiring and connectors for serviceable condition. The connectors must be safetyed where applicable.

An operational check of the tachometer system can only be made by running the aircraft engine. You are reminded that only qualified personnel can operate the engines. As the engines are run, check the tachometer indicator to see that it starts smoothly at low engine rpm and follows the increase and decrease in engine rpm smoothly and accurately. If some malfunction becomes apparent during the operational check, you must troubleshoot and repair the system.

Table 5-1 shows some troubles that commonly arise during the operation of tachometer systems. Study this table. You can see that a multimeter is a good item to use in troubleshooting the system. For example, you have a three-wire tachometer system that is inoperative. Take the electrical connector off the indicator and check the pins with a multimeter. Check pins A to B, A to C, and B to C. Since the generator has a three-phase winding of equal value in each leg, all of the readings will show resistance, provided the wiring and the generator windings are in good condition. There are only two other possibilities that remain: (1) the generator drive is broken or (2) the indicator is defective. The same resistance check can be made from the generator connection through the indicator. Open leads will result in an infinite indication on the meter. For example, if the A lead is open, the B to C lead will give resistance and the A to B lead and A to C lead will read infinity.

TABLE 5-1
TROUBLESHOOTING CHART FOR TACHOMETER SYSTEMS

Trouble	*Probable Cause*	*Remedy*
Reverse reading.	Reversed leads.	Correct the reversed leads.
No indication.	Open lead.	Repair the open lead.
	Shorted leads.	Insulate shorted leads.
	Indicator defective.	Replace indicator.
	Generator defective.	Replace generator.
Pointer oscillation.	Generator defective.	Replace generator.
	Indicator defective.	Replace indicator.
	Poor connections.	Repair connections.
Low reading.	Defective indicator.	Replace indicator.
High reading.	Defective indicator.	Replace indicator.

You must always consult the applicable aircraft TO for the tachometer system wiring connections because not all tachometer systems are connected in the same manner. Generally speaking, the tachometer systems used on reciprocating engines have external grounds. The systems used on jet aircraft have a two-pin electrical connector and an internal ground. A three-pin connector is used on a generator for a reciprocating engine. Up to this point, we have discussed isolating troubles in the tachometer system using a multimeter. On a multiengine aircraft, you can verify a suspected defective indicator by switching it with one known to be good. There is also a tester available for checking system components.

Removal and Installation of Tachometer System Components. Normally, little or no maintenance is required on tachometer systems other than periodic checkouts and inspections. If a component of the system is defective in any manner, it should be replaced. The removal and installation of the indicators was fully covered at the beginning of this volume under maintenance fundamentals.

The engine cowling must normally be removed to gain access to the tachometer generator shown in figure 5-4. Disconnect the electrical connector from its receptacle on the generator. Remove the four self-locking nuts and the washers from the mounting studs at the base of the generator, and remove the generator and the gasket from the engine.

When installing a tachometer generator, install a new, properly lubricated gasket on the mounting studs as instructed in the applicable TO. You should use new self-locking nuts because the locking insert in these nuts loses its locking friction when reused. Install the nuts, with washers, and tighten them to the torque values specified in the TO. Connect the electrical connector to its receptacle and safety it with .020 diameter steel safety wire. Reinstall the engine cowling and perform an operational check on the next engine run.

Exercises (644):

1. What are the inspection requirements for a tachometer indicator?

2. What do you check for during an operational check of a tachometer system?

3. Match the malfunction indications listed in column A with the probable cases listed in column B. Write the correct number in the space provided. Some probable causes may not be used and some may be used more than once.

Column A

Malfunction Indication

____ (1) Tachometer oscillates back and forth at all power settings.

____ (2) On engine start, the tachometer pointers remain at zero.

Column B

Probable Cause

a. Open wire.
b. Defective generator.
c. Incorrect input power.
d. Loose wiring.
e. Reversed wiring.
f. Defective indicator.

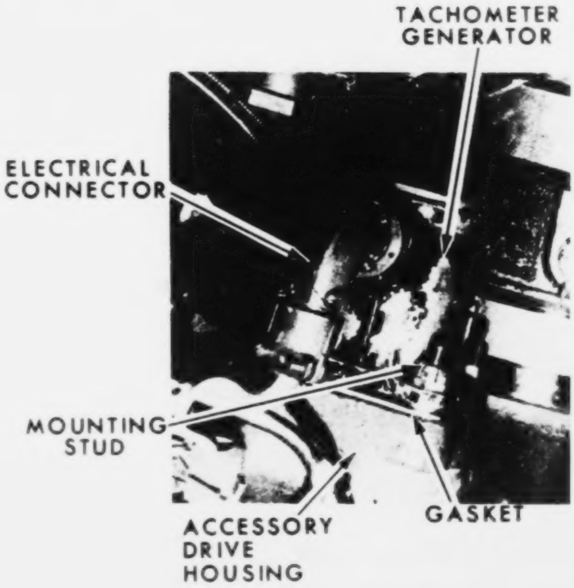

TACHOMETER GENERATOR
ELECTRICAL CONNECTOR
MOUNTING STUD
ACCESSORY DRIVE HOUSING
GASKET

Figure 5–4. Tachometer generator installation.

Column A

Malfunction Indication

Column B

Probable Cause

_____ (3) The tachometer reads slightly lower than the true engine speed.

_____ (4) The tachometer remained at zero while checked with two different indicators. Also, the wiring checked good.

_____ (5) During trouble shooting the tachometer system at the indicator cannon plug, you obtain the following readings: (A–B) 30 ohms; (B–C) infinity; (A–C) infinity

_____ (6) During troubleshooting the tachometer system at the indicator cannon plug, you obtain the following readings: (A–B) 30 ohms; (B–C) 25 ohms; (A–C) 10 ohms.

645. Identify the functions of given tachometer tester components.

Test Equipment. The tachometer tester usually found in instrument shops is the type TTU 27/E. The tester is mounted on a panel assembly. An illustration of a typical TTU 27/E tester is shown in Figure 5-5.

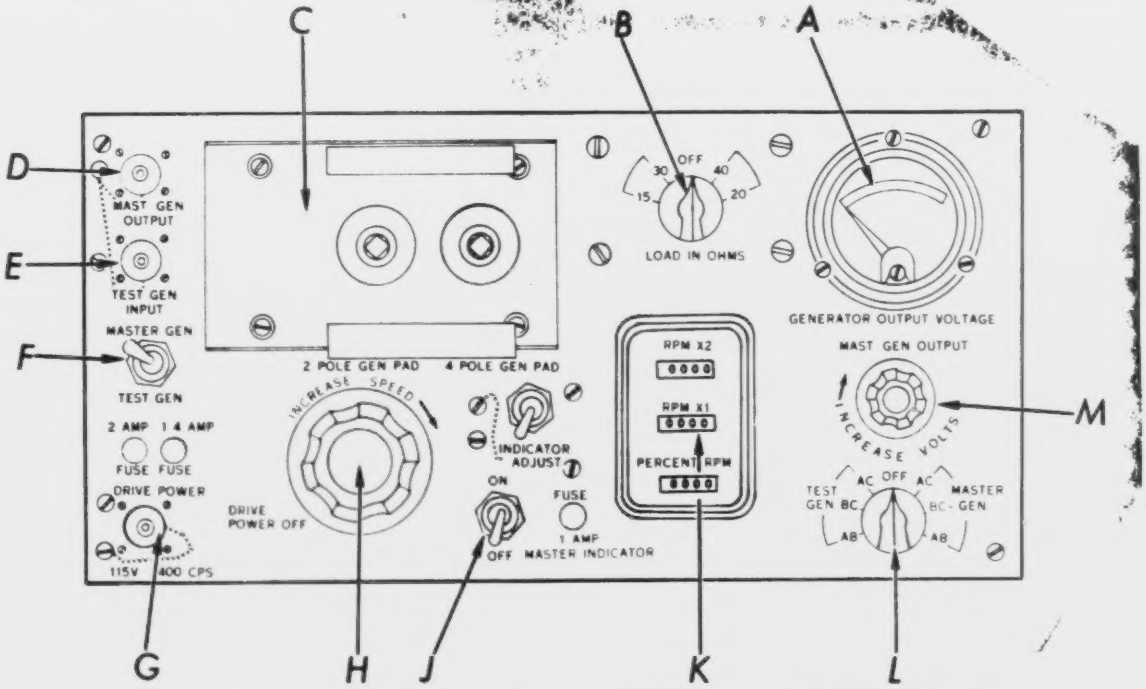

A
B
C
D
E
F
G
H
J
K
L
M
MAST GEN OUTPUT
TEST GEN INPUT
MASTER GEN
TEST GEN
2 AMP FUSE
1 4 AMP FUSE
DRIVE POWER
115V 400 CPS
2 POLE GEN PAD
4 POLE GEN PAD
INCREASE SPEED
DRIVE POWER OFF
INDICATOR ADJUST
ON
OFF
FUSE
1 AMP
MASTER INDICATOR
LOAD IN OHMS
OFF
15
30
40
20
GENERATOR OUTPUT VOLTAGE
RPM X2
RPM X1
PERCENT RPM
MAST GEN OUTPUT
INCREASE VOLTS
TEST GEN
MASTER GEN
AC
OFF
BC
AB

Figure 5–5. Panel of the TTU–27/E tachometer tester.

The two indicators on the tester panel are the voltmeter (A) and the rpm indicator (K). The voltmeter is provided for checking the voltage output of a generator under test or the master generator in the tester. You read either generator voltage output can by positioning the selector switch (L). You can adjust the voltage output of the master generator with the master generator voltage adjust knob (M). The rpm indicator gives the generator speeds in RPM × 1, RPM × 2, and PERCENT RPM. All three counters work simultaneously. This indicator is the standard by which the calibration of 5-15 tachometer indicators is checked.

The generator test pad (C) is provided for mounting the generator to be tested. Either two- or four-pole generators may be mounted on the test pad. Notice in figure 5-5 that the two drive sockets are labeled for two and four poles. The shafts of the test pad are driven by the tester drive motor. Drive motor speed is controlled by the INCREASE SPEED control (H). When the INCREASE SPEED control is turned fully counterclockwise, the drive motor is deenergized. As the control is turned clockwise, the drive motor becomes energized. Its rpm can be controlled from 0 to 5,000 rpm as read on the RPM × 1 indicator. Use the INCREASE SPEED control when testing both indicators and generators.

The three remaining switches on the tester panel are the master switch, the generator test switch, and the load switch. The master switch (J), when in the ON position, supplies power to the tester rpm indicator. Place the switch in the ON position when the tester is in use. The generator test switch (F) selects the input to the rpm indicator. By positioning this switch, you can read the rpm of the test generator or the master generator on the tester rpm indicator. Place this switch to the MASTER GEN position when testing an indicator. You can then compare the readings of the indicator under test to the readings of the tester. When checking a generator, place the switch to the TEST GEN position. The test generator then supplies the input to the rpm indicator and voltmeter, permitting a check of the generator. Use the load switch (B), when testing generators, to connect either a delta- or wye-connected three-phase load to the generator under test. Its position depends upon the type of stator used in the test generator and is shown in the applicable generator TO.

Three electrical receptacles (D, E, and G) are located on the left side of the tester. The power receptacle (G) allows connection of a 115-volt, 400-Hz, single-phase, AC power source to the tester. The test generator receptacle (E) is provided for connecting the generator under test to the tester. Connect tachometer indicators to be tested to the master generator receptacle (D). You must be very careful to connect the power input to the proper receptacle because all three of the electrical connectors are identical. Applying 115 volts to the master generator output or the test generator input can seriously damage the tester.

Step-by-step instructions for the use of the TTU 27/E tester are provided inside the cover lid. Always check the TO for the tester you are using to insure that the instructions are current.

Because complete instructions for using the TTU 27/E are provided in the TO, only one typical bench check is discussed in the following paragraphs. Our example is the bench check of a tachometer generator. Prior to the actual bench check, you prepare the tester for use by complying with the following steps:

(1) Turn increase speed control (H) fully counterclockwise.
(2) Place master switch (J) to OFF.
(3) Place load switch (B) to OFF.
(4) Place voltmeter selector switch (L) to OFF.
(5) Connect tester to a 115-volt, 400-Hz, single-phase, AC power source.

CAUTION: Do not operate the tester until the ground lead of the male connector has been grounded.

Before you can make any bench test of a generator, you must have its test specifications. You can find these in the TO for the generator. The TO lists pertinent information which you will use during the test. For example, the TO lists the number of poles, voltage output per drive shaft rpm for a given load, and stator resistance values. For purposes of clarity, let's state the test specifications of a typical generator. You will see how these specifications are used during the test. Specifications for generator P/N H60–000 are:

- Two-pole rotor.
- Voltage output (wye connected) 4,200 rpm, 40-ohm load, 21 ± .5 volts each phase.
- Voltage output (wye connected) 1,000 rpm, 20-ohm load, 3.5 volts each phase.
- Stator resistance at 77° F., 25 ± 5 ohms each phase.

Now that we have the generator specifications, let's go through the step-by-step procedures for testing the generator with the TTU 27/E tachometer tester. The procedures are done in this order:

(1) Mount the generator to be tested on the test pad. Make sure you use the proper drive socket (two-pole or four-pole).
(2) Connect the test generator to the test generator receptacle with the correct adapter cable.
(3) Turn master switch to ON. Allow 5-minute warmup period.
(4) Slowly turn the INCREASE SPEED control clockwise until the desired generator drive speed is indicated on the RPM × 1 indicator (in this case, 4,200 rpm).
(5) Place the load switch to the appropriate position (in this case, 40 ohms).
(6) Turn the voltmeter selector switch to the AC, BC, and AB positions and note the voltmeter readings. These readings should meet the specifications for the test generator. (In this case, 21 ± 5 volts for each phase).
(7) Slowly turn the INCREASE SPEED control counterclockwise until the desired lower rpm is indicated. (In this case, 1,000 rpm).
(8) Place the load switch to the appropriate position (in this case, 20 ohms).
(9) Repeat step (6). In this test, the voltmeter reading should be not less than 3.5 volts for each phase.
(10) Turn the INCREASE SPEED control fully counterclockwise and all other switches off.

The procedures followed to bench check a four-pole generator are the same as those followed for a two-pole generator with one exception. The generator drive speed (step 4) for a four-pole generator is obtained when the RPM × 1 indicator reads double the desired drive speed. This completes our discussion of the tachometer generator bench test. If the generator meets the TO specifications, it is considered serviceable. However, if the generator does not meet the specifications, it must be repaired by following the instructions given in the applicable overhaul TO.

Exercises (645):

1. Match the tachometer tester components listed in column A with their functions listed in column B. Write the correct letter in the space provided. Some functions listed are not used.

Column A
Components

_____ (1) TTU-27/E.
_____ (2) Voltmeter.
_____ (3) RPM indicator.
_____ (4) Selector switch.
_____ (5) Voltage adjust knob.
_____ (6) Generator test pad.
_____ (7) Increase speed control.
_____ (8) Master switch.
_____ (9) Generator test switch.
_____ (10) Load switch.
_____ (11) Test generator receptacle.
_____ (12) Master generator receptacle.
_____ (13) Power receptacle.

Column B
Functions

a. Indicates the amperage load output of a generator under test.
b. Allows for connecting the generator under test to the tester.
c. Used for selecting test or master generators.
d. Provides mounting for two- or four-pole generators.
e. Selects the input to the rpm indicator.
f. Monitors voltage output of tachometer indicators.
g. Allows for connecting the indicator under test to the tester.
h. Indicates output of generators in rpm percent.
i. Provides the means for supplying power to the master indicator.
j. Allows for connecting an external strobotac to the tester.
k. Allows connection of a power source to the tester.
l. Connects a delta or wye load to the generator under test.
m. Controls dive motor speed.
n. Adjusts master generator output.
o. Monitors voltage output of tachometer generators.
p. Tests tachometer system components.

5-2. Thermocouple Thermometers

Earlier in this course, you learned that electrical power could be generated by chemical action (as in storage batteries) and by moving a conductor through a magnetic field. Thermocouple systems obtain their required power by yet another means.

646. State the thermocouple principle and the uses of thermocouples.

Thermocouples. The thermocouple is the sensing element of the system. It generates the electrical power needed for the system. The electromotive force (emf) generated by the thermocouple is in DC millivolts. It is, however, sufficient for correct operation of the system. The method by which the emf is generated is quite different from the chemical or mechanical action of a battery or a generator. We will first explain the thermocouple principle, then show you how it is used to measure temperature.

When the ends of two wires of unlike metals are fused together and heated, an electromotive force is generated. The fused end of the wire is known as a *thermocouple*, or *hot junction*. The circuit is completed by connecting a millivoltmeter to the other ends (cold junction). The amount of current flow generated by such a circuit depends upon the difference in temperature between the two junctions. Now, suppose that each degree of temperature difference between the hot and cold junction produces 1 millivolt. You can see that it would be quite a simple matter to convert the millivoltmeter to a differential temperature indicator. But, hold on; this indicator is measuring differential temperature. What we need is true temperature. When we fasten the thermocouple to the cylinder of an engine, we want to know the exact temperature of that cylinder—not the difference between the cylinder head and cabin temperature. We can get the information we want by attaching a bimetallic spring to the pointer of the meter. Such a device will cause the pointer to act like a thermometer. If we were to place this instrument in the aircraft, it would indicate the temperature of the cabin. So we now have established a new reference (starting) point, one that is determined by the temperature of the cabin. When we connect the meter to the thermocouple leads, the indication shown on the meter will be the cabin temperature plus the difference between the cabin temperature and the hot junction, thus giving us the true temperature of the hot junction. Now let's look at the components of the system.

Certain combinations of metals produce an emf increase that is directly proportional to the heat applied for a particular temperature range. The combinations most commonly used are iron-constantan, copper-constantan, and chromel-alumel. The iron or copper-constantan combinations are generally used for lower temperature situations. Chromel-alumel will be found where higher temperatures, such as jet exhaust, are encountered.

Constantan is an alloy containing 60 percent copper and 40 percent nickel. Chromel is an alloy of 90 percent nickel and 10 percent chromium. Alumel contains 95 percent nickel plus aluminum, silver, and manganese.

There are three basic thermocouples in use today. Each type uses one of the combinations of metal that we have mentioned. There is the gasket-type thermocouple which is used to measure cylinder-head temperature on reciprocating engines. It is positioned under the spark plug of the hottest running cylinder of the engine.

The second type of thermocouple is the bayonet type. It is adaptable to many installations. Two common temperatures measured with this thermocouple are bearing and cylinder-head temperatures. A special adapter is used to mount this thermocouple.

The third and most common type is one that is housed in a flange-mounted protective probe. It is used to measure the exhaust gas temperature of jet engines. Depending upon the engine, the probe may contain one or two individual thermocouples. Figure 5-6 illustrates a two-element flange-mounted probe. Notice that the two thermocouples (A) are mounted inside the probe housing (B). The probe is inserted into the exhaust case of the engine as shown in figure 5-7 and held securely by two bolts. These bolts extend through the mounting flange and holes (C and E). The thermocouples are connected to the thermocouples leads (harness) by the terminal posts (D), also shown in the top view of figure 5-6 as F and G. The small ports (H) in the probe allow the hot gases to reach the thermocouples. The protective probe around the thermocouples aids in reducing their erosion. This erosion is caused by the extremely high gas temperatures and the carbon particle discharge from the engine.

When the flange-mounted probe is used, three or more of the probes are evenly spaced around the engine exhaust section. The exact number used depends upon the type of engine.

Exercises (646):

1. What is the thermocouple principle?

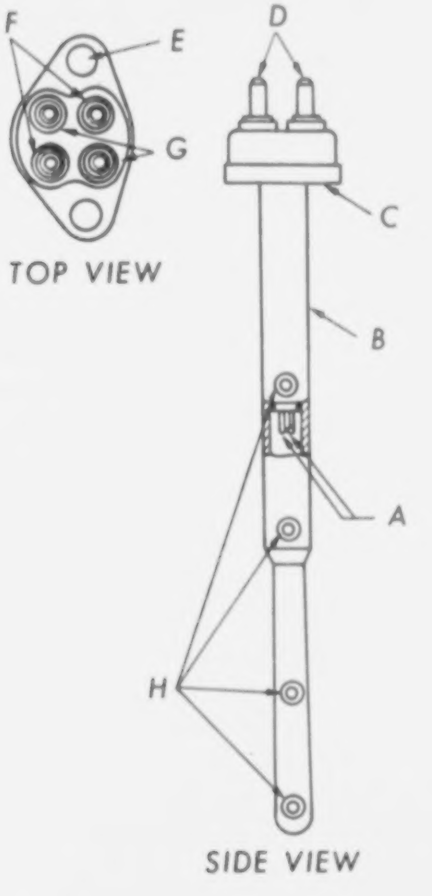


Figure 5-6. Dual element thermocouple.

2. Why are chromel-alumel thermocouples used in jet engines?

3. What type of thermocouple is used to measure cylinder head temperature on a reciprocating engine?

4. Where are the thermosouples mounted in jet engines?

5. What is required to obtain a true temperature measurement instead of a differential temperature measurement using a thermocouple system?

647. Specify the functional characteristics of thermocouple leads.

Thermocouple Leads. Special leads connect the units of a thermocouple system. These leads are made of the same materials used in thermocouples, but in a given usage the thermocouple and leads may not be made of the same matrial. Many aircraft use chromel-alumel thermocouples and wiring on the engine, and iron-constantan or copper-constantan wiring from the engine to the indicator in the cockpit. The temperatures to which the leads are exposed and the amount of lead resistance required for system operation determine the type of material used. All thermocouple leads must have a constant amount of resistance; therefore, AF-type thermocouple leads are made in sets for each different type of aircraft. The following features of each set are fixed: size of wire (diameter), length, connections, and resistance value to within ± O.01 ohm. Some thermocouple systems use as many as four sections connected together to complete the system. They can, however, be individually ordered, as each section has its own stock number. Each section consists of two individually insulated conductors within a common insulation. The insulating materials are not affected by fuel, oil, or water. Some sets of these leads can be used in several different types of aircraft as long as the resistance is correct. Any excess wire can be coiled and secured to the aircraft structure. You should never cut this type of lead. Cutting it will change the resistance, and any change in resistance will make the reading inaccurate.

The most common type of lead in use is the AN type. This type of lead is adaptable to different circuits, since no specific length is required. It can be neatly cut to the desired size for the installation. The system must have a very accurate and definite amount of resistance. The systems commonly used call for either two-, 8-, or 22-ohm total lead resistance, ± 0.1 ohm. Since practically no two aircraft will have the same lengths of wire, you may wonder how the resistance is stabilized. An AN-type resistor is installed in the negative lead of the system. It is adjusted to the

618

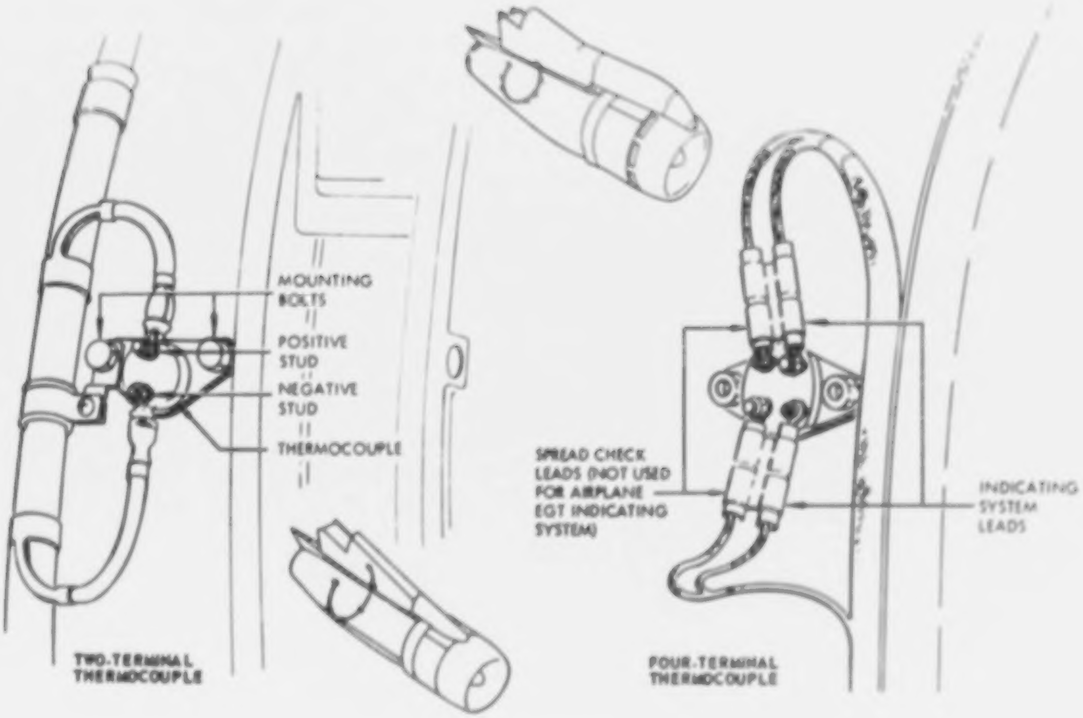

MOUNTING BOLTS
POSITIVE STUD
NEGATIVE STUD
THERMOCOUPLE
TWO-TERMINAL THERMOCOUPLE
SPREAD CHECK LEADS (NOT USED FOR AIRPLANE EGT INDICATING SYSTEM)
INDICATING SYSTEM LEADS
FOUR-TERMINAL THERMOCOUPLE

Figure 5-7. Thermocouple installations.

desired resistance. Because of the fixed and different resistances of each lead, this is one type of two-wire system in which reversed leads will definitely affect the accuracy of the system. To prevent their becoming crossed, both the lead and the thermocouple wires are color-coded according to the metal used.

Two types of variable resistors are used with the AN-type leads. Regardless of which type is used, it must always be connected to the negative lead of the circuit. One type (fig. 5-8) consists of two spools of wire mounted on a phenolic block. The wire is rated at approximately 0.7 ohm per foot, and usually only one spool is used in the circuit. The second spool is a spare. To get the correct amount of resistance in the circuit, remove wire from the spool until the desired total resistance for the circuit is obtained.

The second type of variable resistor (see fig. 5-9) consists of a fixed 4-ohm resistor and a variable four-ohm resistor with a sliding contact. The sliding contact permits adjustment of the variable resistor. A screw on the sliding contact allows you to secure it after you have set the correct resistance.

The TO that discusses thermocouple leads states that the resistance of the leads cannot vary from the required resistance by more than 0.1 ohm. The required resistance of the circuit can be found on the back of the indicator. All thermocouple indicators have the required circuit resistance stamped near the terminal connections. A method of checking lead resistance will be explained later.

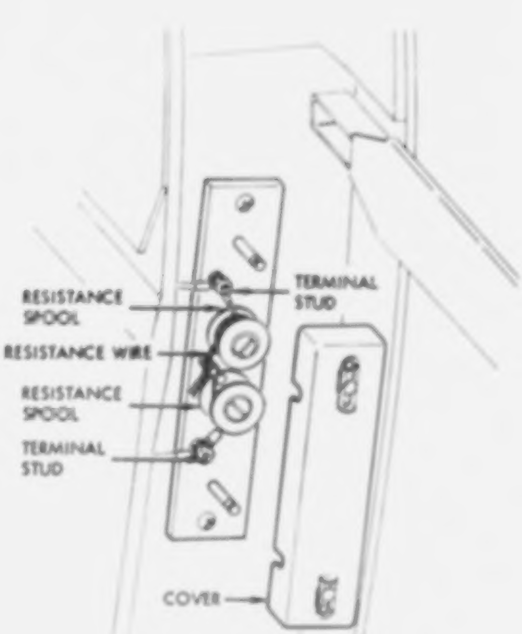

RESISTANCE SPOOL
TERMINAL STUD
RESISTANCE WIRE
RESISTANCE SPOOL
TERMINAL STUD
COVER

Figure 5-8. Resistance spools used in thermocouple systems.

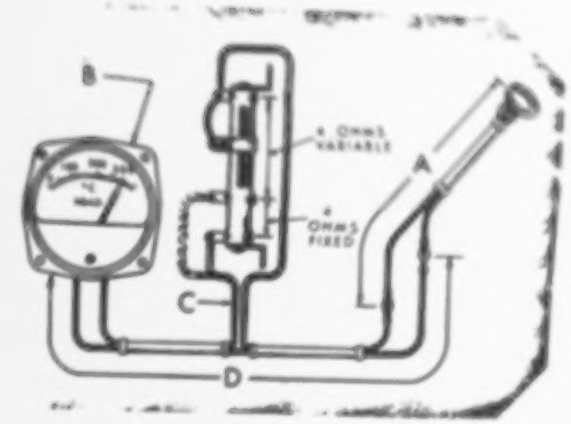


Figure 5-9. Thermocouple thermometer system.

Exercises (647):

1. List the fixed features of AF-type thermocouple leads made for a specific aircraft.

2. Give two factors which determine the type of material used in thermocouple leads.

3. Why should you *never* cut and splice a thermocouple lead?

4. When using AN-type thermocouple leads, how is the required circuit resistance obtained and maintained?

5. How do you determine the amount of lead resistance required

648. Identify the functions and operations of components of the thermocouple indicator.

Thermocouple Indicators. The thermocouple indicators in use today are constructed to indicate temperatures for several different ranges up to 1,200° C. While the dials of the indicators may appear similar, the internal movements of the indicators can be quite different. The indicator movements generally fall into two categories: the D'Arsonval meter movement and the basic servomechanism types.

The D'Arsonval movement type indicator is basically a sensitive D'Arsonval millivoltmeter. Instead of the dial's being calibrated to indicate millivolts, it is calibrated to indicate temperatures. You should recall that the D'Arsonval meter operates from current flowing through a moving coil. In the thermocouple system, the current flow is a result of heat applied to the thermocouples. From these two statements, you can see that the D'Arsonval movement, when connected to a thermocouple, functions as a temperature indicator. A typical D'Arsonval indicator is shown in figure 5-9. More will be said about this figure later in this section.

Although the D'Arsonval movement is the major unit in the indicator, other elements are needed for correct system operation. Figure 5-10 shows an internal schematic of a single D'Arsonval-type indicator. Of course, there must be some method of conducting current to and from the movement. The hairsprings (A and G) do this job. They also restrict pointer movement so that the pointer deflection is proportional to the current flow in the circuit. The unit used to compensate for temperature changes at the indicator is the bimetallic spring (F) connected to one of the hairsprings. A screw on the back of the indicator is attached to the bimetallic spring to permit adjustment of the indicator to ambient temperature. The pointer should indicate the temperature of the air surrounding the indicator.

As you know, an increase in temperature causes an increase in resistance in most material. We have already stated that the resistance must remain constant throughout the electrical circuit; consequently, there must be some means of compensating for the added resistance due to temperature rise. This compensation is provided by adding a negative temperature coefficient resistor of carbon (D). This resistor is installed inside the indicator in series with the moving coil (H). Since carbon has a negative temperature coefficient, its resistance decreases as its temperature goes up. As a result of its use, then, the resistance in the circuit will remain constant.

Thermocouple indicators have varying ranges and are used in systems having more than one thermocouple. Therefore, some means must be incorporated to calibrate the indicator. This is done by the calibrating resistor (C). The resistor is adjusted so that the indicator reads a given temperature for a given millivoltage applied between the positive and negative terminals (B and E). These values can be found in the TO for each indicator.

The servomechanism-type indicator is used to measure exhaust gas temperature on jet engines. This type of indicator has three advantages over the D'Arsonval type. First, it responds quicker than the D'Arsonval type to

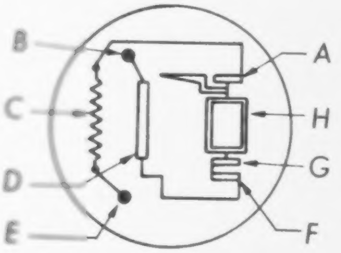


Figure 5-10. Simplified drawing of a single thermocouple indicator.

changes of temperature at the thermocouples. Second, the indicator does not have to be set to ambient temperature to be accurate. Third, the resistance of the thermocouple harness (wiring) is not as critical as for the D'Arsonval-movement type. However, the indicator has one disadvantage. The servomechanism-type indicator requires 115-volt, 400-Hz power from the aircraft power source. This means that an emergency power source must be provided to the indicator so that it will operate in the event of a power failure on the aircraft. Figure 5-11 shows a block diagram of a basic servomechanism indicator.

The indicator consists of a cold junction compensator, a power-off flag mechanism, a servoloop, and two bulbs for internal lighting. The compensator provides a constant reference temperature at the cold junction by compensating for variations in ambient temperature. The power-off flag mechanism actuates a rotating drum with the word "OFF" printed on it. When power is applied to the indicator, the drum rotates against spring tension. The word "OFF" disappears from the window on the indicator dial. If power to the indicator fails, the spring unwinds. The drum then rotates to show the word "OFF" on the dial of the indicator. The power supply provides the operating voltages for the remaining units in figure 5-11 which make up the servoloop. A stepdown transformer on the aircraft provides 5-volt AC power to the internal lighting circuit.

When the servomechanism-type indicator is used in the EGT system, three or more themocouples are used to provide the signal to the indicator. In most cases, 6 or 12 dual thermocouple probes are used. Figure 5-12 shows how

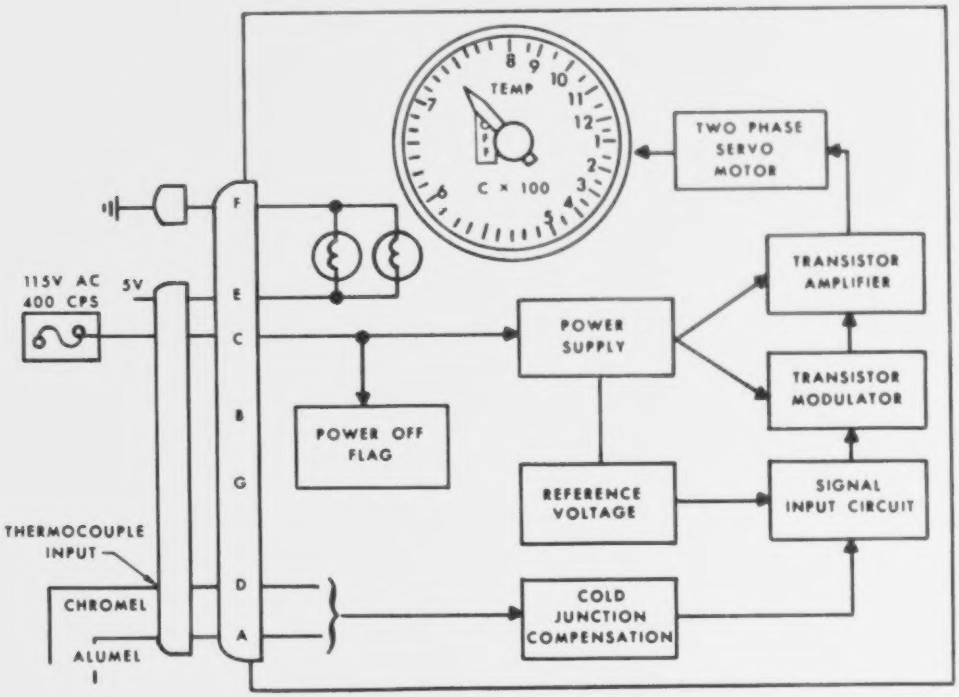

TEMP
8
9
10
11
12
1
2
3
4
5
6
7
C × 100
TWO PHASE SERVO MOTOR
F
E
C
B
G
D
A
115V AC 400 CPS
5V
TRANSISTOR AMPLIFIER
POWER SUPPLY
TRANSISTOR MODULATOR
POWER OFF FLAG
REFERENCE VOLTAGE
SIGNAL INPUT CIRCUIT
THERMOCOUPLE INPUT
CHROMEL
ALUMEL
COLD JUNCTION COMPENSATION

Figure 5–11. Flow diagram of a servoed thermocouple indicator.

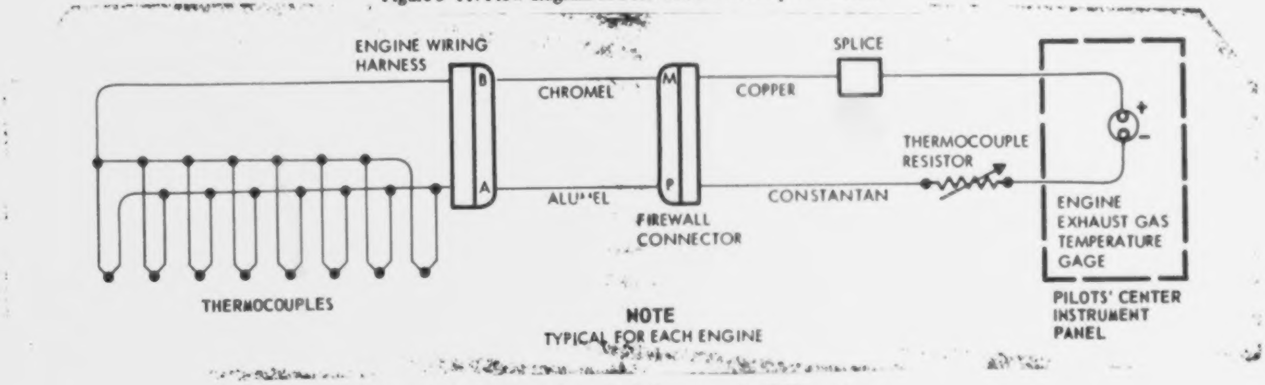

ENGINE WIRING HARNESS
B
A
CHROMEL
ALUMEL
M
P
FIREWALL CONNECTOR
SPLICE
COPPER
THERMOCOUPLE RESISTOR
CONSTANTAN
+
−
ENGINE EXHAUST GAS TEMPERATURE GAGE
PILOTS' CENTER INSTRUMENT PANEL
THERMOCOUPLES
NOTE
TYPICAL FOR EACH ENGINE

Figure 5–12. Diagram of a multiple thermocouple (EGT) system.

the thermocouples are connected to the EGT system. Notice that the thermocouples are connected in parallel with the EGT indicator. With the thermocouples connected in this manner, the DC signal input to the indicator will be a millivolt signal equal to the average temperature of the exhaust gases. The other set of thermocouples in a dual element probe may be connected to a fuel control amplifier or to a test receptacle on the engine. Now that you are more familiar with the construction of the different types of thermocouple indicators, we shall study how they operate in the system.

Exercises (648):

1. Match the components of the thermocouple indicator listed in column A with their functions/operations listed in column B. Write the correct letter in the space provided. Some functions/operations are used more than once and some may not be used.

Column A

Components

_____ (1) D'Arsonval movement.
_____ (2) Hairsprings.
_____ (3) Bimetallic spring.
_____ (4) Negative coefficient resistor.
_____ (5) Calibrating resistor.

Column B

Functions/ Operations

a. Compensates for temperature changes at the indicator.
b. Responds to voltage changes.
c. Operates on the principle of a balanced bridge circuit.
d. Resistance decreases as temperature increases.
e. Conduct current to and from meter movement.
f. Resistance decreases as temperature decreases.
g. Supplies the correct millivolts for the indicator.
h. Provides for manual adjustment for ambient temperatures.
i. Adjusts indicator to read a given temperature at a given applied voltage.
j. Restrict pointer movement to a proportional amount.
k. Compensates for temperature changes througout the circuit.

2. What temperature systems use the servomechanism temperature indicator?

3. List the advantages of the servomechanism indicator over the D'Arsonval movement thermocouple indicator.

4. Why is an ambient temperature adjustment not necessary on the servomechanism thermocouple indicator?

5. When two or more thermocouples are used in a system, how are they connected in the system? Why?

649. Specify the operational characteristics of the thermocouple thermometer system.

Since the operation of the two types of thermocouple indicators are so different, we will discuss each of them separately. We will discuss the D'Arsonval-movement indicator first.

D'Arsonval-movement type. The thermocouple system operates on the voltage generated between the hot and cold junctions. The voltage generated determines the amount of current flow in the curcuit. As the current flows through the indicator, it actuates the D'Arsonval movement and actually measures the current flowing in the circuit. However, the indicator dial is calibrated in degrees C.

The use of the carbon resistor and the bimetallic spring allows an accurate indication of the temperature at the hot junction to be made. Figure 5-9 shows you a typical hookup for a thermocouple system. Note that the constantan lead (C) is negative and the iron lead (D) is positive. This holds true throughout the system, and the current flows from negative to positive. At any point where the two metals are joined, a thermocouple (A) exists. The indicator (item B) and the resistor complete the circuit.

Using the schematic drawing of a thermocouple system, let's determine what actually occurs during operation of the system. We will use hypothetical values for our discussion.

Suppose that the temperature at the indicator (B) in figure 5-9 is 30° and the temperature at the thermocouple is 150°. The difference in the temperature of the two junctions is 120°. We will assume that .1 millivolt of energy is generated for each degree of temperature difference. We can then say that 12 millivolts are generated by the thermocouple. This current flow causes the pointer to be deflected to indicate 120° C. But the bimetallic spring has already compensated for the 30° existing in the cabin, so the pointer will indicate the true temperature at the thermocouple, 150° C.

Thus far we have discussed a thermocouple system containing one thermocouple. When more than one thermocouple is used (EGT systems), they are connected in parallel, as shown in figure 5-12. With thermocouples connected in parallel, the total voltage generated is the average voltage of all the thermocouples. This means that the thermocouple indicator shows the average temperature of the hot gases in the engine exhaust.

Servomechanism Type. The servomechanism system, like the D'Arsonval system, operates on the voltage generated between the hot and cold junctions. However, the servomechanism indicator operates quite differently from the D'Arsonval type. The thermocouple circuit output to the servomechanism indicator is a DC millivoltage. This voltage is compared to a reference voltage in the indicator (cold junction) and is proportional to the degree of heat applied. The cold junction reference voltage is held at a constant value by the cold junction compensator.

The output of the thermocouple circuit is compared to the reference voltage in the signal input circuit. This is shown in figure 5-11. The reference voltage is provided from the wiper of the servomechanism rebalance potentiometer. When the signal voltage is of lesser or greater magnitude than the reference voltage, the difference between the two voltages is detected in the signal input circuit, which is a servo-driven self-balancing bridge network. The difference is then amplified and applied to a servomotor in the indicator. The difference between the thermocouple voltage output and the reference voltage from the rebalance potentiometer wiper is the error signal that is applied to the transistor modulator. For example, the average voltage output of the thermocouples is 28 millivolts. The difference voltage from the wiper of the rebalance potentiometer is 28 millivolts. The difference between the two voltages is zero (0). In this case, no error signal is applied to the modulator circuit. The servoloop is at null. However, let's say that an increase in exhaust gas temperature causes the thermocouple circuit output to go up 30 millivolts. Now the difference between the two voltages is 2 millivolts. The error signal applied to the modulator is 2 millivolts.

The 2-millivolt DC error signal is chopped (changed to a 2-millivolt AC error signal) in the modulator circuit. The AC signal is then amplified to the strength necessary to drive the servomotor by the transistor amplifier. As the servomotor drives, mechanical linkage positions the indicator pointers to show the increase in temperature. At the same time, the mechanical linkage positions the wiper of the rebalance potentiometer to produce a 30-millivolt output. At this time, the bridge is balanced; the reference and the thermocouple output voltages are equal. No error signal is present and the servomotor stops. The servoloop is again nulled.

These indicators may also contain a simple synchro transmitter to provide signal voltages for driving a synchro repeater indicator in order to give a simultaneous display of this temperature at another location.

The resistance of the thermocouple circuit to the servomechanism indicator is not critical. Therefore, no external resistor is used in the circuit. On some aircraft, this resistance can be between 5 and 100 ohms without causing the system to function abnormally. This completes our discussion of thermocouple system operation.

Exercises (649):

1. In a thermocouple system using iron-constantan leads, which lead is connected to the positive terminal of the indicator?

2. If the temperature at the cold junction of a D'Arsonval movement is 20° and the temperature at the thermocouple is 180°, what will the indicator read?

3. How is an error signal developed in the signal input circuit of the servomechanism indicator?

4. How is the error signal cancelled in the servomechanism indicator?

5. What is not critical on the servomechanism indicator that is critical on the D'Arsonval indicator?

650. State inspection, removal and installation, and operational check procedures, and identify the malfunction to expect with given hypothetical troubles.

Inspection. On preflight inspections, check the indicator for broken, loose, or chipped cover glass. Check it also for proper range markings. In addition to the previously mentioned items, examine the servomechanism indicator for power-off flag operation. The indicator readings should be consistent with known temperatures.

On major inspections, check the indicator for security of mounting. Check the leads for mounting and insulation condition; and check the terminals for clean, tight connections. The leads may also be checked for proper resistance. Check the thermocouples visually for external damage.

Operational Check. To adequately perform an operational check on a thermocouple system, you must operate the system of which the temperature is being measured. In most cases, thermocouple systems are used to measure engine temperatures (bearing, cylinder head, and exhaust gas temperatures). Therefore, the engines must be operated. If the servomechanism indicator is installed, make sure the indicator is receiving the required power from the aircraft power source. Check the indications for accuracy while the engines are operating. Because the operating temperatures of the engines vary with different aircraft, you are required to check the aircraft TOs to determine the normal operating temperatures for existing conditions.

It is important for you to know that, when the engines are operated, the aircraft must be turned into the wind. A crosswind or tailwind can cause abnormal indications of cylinder head and exhaust gas temperatures.

On most jet aircraft you can perform an operational check of the EGT system without operating the engines. You make this check by using the Jetcal tester, which is discussed later in this chapter. If abnormal temperatures occur during the operational check, troubleshoot and repair the system.

Removal. Anytime you remove a D'Arsonval-movement type of thermocouple indicator, make sure that the aircraft leads are clearly marked so that the indicator can be installed correctly. If the leads are crossed, the indicator will run backwards. Also connect a shorting wire across the terminal post. This dampens the pointer movement during transportation and helps prevent damage to the indicator.

Installation. In addition to the fundamentals of instrument systems maintenance which we covered in Chapter 1 of this volume, make sure that the correct polarity is observed when connecting the thermocouple leads. Seal the adjustment on the indicator with antitamper compound to prevent aircraft vibrations from altering the adjustment.

Troubleshooting. When troubleshooting any type of thermocouple system, you must have an idea of the troubles that are likely to occur. Certain indications usually identify the trouble that exists. You must be able to recognize these indications, locate the trouble, and make the necessary repairs. Some of the most frequent troubles that occur in the D'Arsonval-movement type systems are shown in table 5-2.

The most frequent troubles in the servomechanism-type system are the indicator's being inoperative, driving continuously off-scale low, or reading high or low. When the indicator is inoperative, check to make sure that it is receiving power from the aircraft power source. If it is, the indicator is defective and must be replaced. If the indicator drives off- scale low, the probable trouble is an open lead from the thermocouples. In this case, the indicator will not receive the thermocouple output and the servoloop will not null. When the indicator is suspected of reading high or low, a complete check of the system is required. The best way you can do this is by using the Jetcal tester to simulate engine heat at the thermocouples. This test insures that the trouble is not in the engine.

If you find that the trouble is in the indicating system, the trouble can be in one of two categories. First, if the indication is high, the indicator is out of calibration and you must replace it. A defective thermocouple will rarely cause the indicator to read excessively high, but it could. Because several thermocouples are used to obtain an average temperature, the failure of a cooler the that average just as the failure of a hotter thermocouple could lower that average. Also, for this reason, the failure of one or more thermocouples can often go undetected until a heat rise check is performed.

Now, if the indicator reads low, it could be out of calibration; however, the most probable cause would be a defective thermocouple circuit. Normally, a defective thermocouple will cause a low reading.

TABLE 5–2
TROUBLESHOOTING CHART FOR THERMOCOUPLE SYSTEMS

Trouble	*Probable Cause*	*Remedy*
Indicator reads ambient temperature only.	Open leads.	Repair or replace leads.
	Open resistor.	Repair or replace resistor.
(Single thermocouple systems)	Open thermocouple.	Replace thermocouple.
	Open circuit in indicator.	Replace indicator.
High or low indication.	Ambient temperature or zero adjustment improperly set.	Adjust indicator as stated in TO.
	Resistor improperly adjusted.	Check resistance of circuit and adjust.
Consistent low indications.	Poor connection in external circuit.	Check connections for tightness and cleanliness.
	Resistor improperly adjusted.	Check resistance and adjust if necessary.
(Multi-thermocouple systems)	One or more thermocouples defective.	Replace defective thermocouples.

Malfunction in engine operation or incorrect adjustments on the engine result in indications that make it look like the indicating system has failed. For this reason, you must work closely with the jet engine mechanics. You must also be very thorough in inspecting, testing, and troubleshooting the exhaust gas temperature indicating system. Your knowledge of the thermocouple systems and the experience you gain in troubleshooting them will help you determine if an incorrect indication is caused by a problem in the indicating system or in the engine.

Eventually, you will have enough knowledge and experience to make such determinations while debriefing the pilot. At most bases, the aircraft pilot meets with maintenance specialists to discuss problems experienced during flight. This procedure is very helpful in troubleshooting engine instruments and other complex systems. Suppose for example, that the pilot says that the EGT indication was high. In the discussion, you find out that the fuel flow, the EPR, and the RPM indications were also high. This is a good indication that someone needs to check the engine and that there is nothing wrong with the indicating system. On the other hand, if the EGT was high and the other systems' indications were normal, then the problem is definitely in the indicating system.

The maintenance data collection system can also be a valuable aid in troubleshooting. It has been proven that when engine performance is recorded and compared to past performance, minor problems can be detected and corrected before they develop into major problems, such as complete engine failure. An engine condition monitoring program uses information obtained through the MDC system and from the pilots to give us warnings of engine or instrument systems failure. For example, a continuous drop of ° or 10° in exhaust gas temperature for each flight while the other engine instrument indications remain normal for each flight indicates that something is wrong with the indicating system and will probably get worse. The same temperature indications accompanied by a gradual decrease in thrust or RPM would probably be a good indication of a problem developing in the engine.

Finally, and most important, the item most helpful in troubleshooting a thermocouple system will always be your aircraft TO. Always use the TO when performing maintenance on a thermocouple system.

Exercises (650):

1. State what you check for when performing a preflight inspection of a thermocouple thermometer system.

2. State the considerations that should be given to the prevailing winds when operationally checking thermocouple EGT systems.

3. Match malfunction indications listed in column A A with the most likely hypothetical trouble(s) listed in column B. Write the correct number in the space provided. Some hypothetical troubles are used more than once.

Column A

Malfunction Indications

_____ (1) Thermocouple indicator reads high.
_____ (2) Thermocouple indicator reads low.
_____ (3) Thermocouple indicator reads ambient temperature only.
_____ (4) Thermocouple indicator fluctuates.
_____ (5) Servomechanism indicator inoperative.
_____ (6) Servomechanism indicator reads off-scale low continuously.
_____ (7) Servomechanism indicator reads low.
_____ (8) Servomechanism indicator reads high.

Column B

Hypothetical Troubles

a. Wiring resistance too high.
b. Open wiring.
c. Open power source.
d. Corroded connections.
e. Defective indicator.
f. Improperly adjusted resistance spool.
g. Shorted wiring to ground.
h. Loose wiring.
i. Defective thermocouple.
j. Improperly adjusted indicator.

651. Identify the functions and descriptions of components of the N–3A tester.

Test Equipment. Various items of test equipment are available to aid you in troubleshooting thermocouple systems. The testers most commonly found in instrument shops are discussed later in this chapter. But first a warning! A multimeter should not be used to check the resistance of the indicator or the thermocouple circuit. If the multimeter is used to check the resistance of the indicator, too much voltage will flow through the D'Arsonval movement. This may damage the indicator. If the multimeter is used to check the resistance of the thermocouple circuit, the indications will not be accurate enough. To insure the desired accuracy, you must use an N–3A thermometer tester, a Jetcal tester that or a Wheatstone bridge. Remember, you must disconnect the leads from the indicator any time a resistance check is made. Take a look now at some of the most common thermometer testers.

N–3A thermometer tester. The N–3A thermometer tester is used to check the calibration of the D'Arsonval-movement indicators, the thermocouple circuit for resistance, and the calibration of the ratiometer-type resistance thermometer indicators. Since the ratiometer-type thermometers are covered later in this chapter, we will only discuss the use of the tester in the thermocouple system.

The tester is mounted in a portable carrying case. The case interior is divided into three sections. The one at the left is the battery section. In this section is located a 45-volt and a 1.5-volt battery. Since the tester has its own power source, it is completely portable. The center section contains the tester control panel shown in figure 5-13. The right section is the storage space for the various test cables supplied with the tester. A glass thermometer is mounted

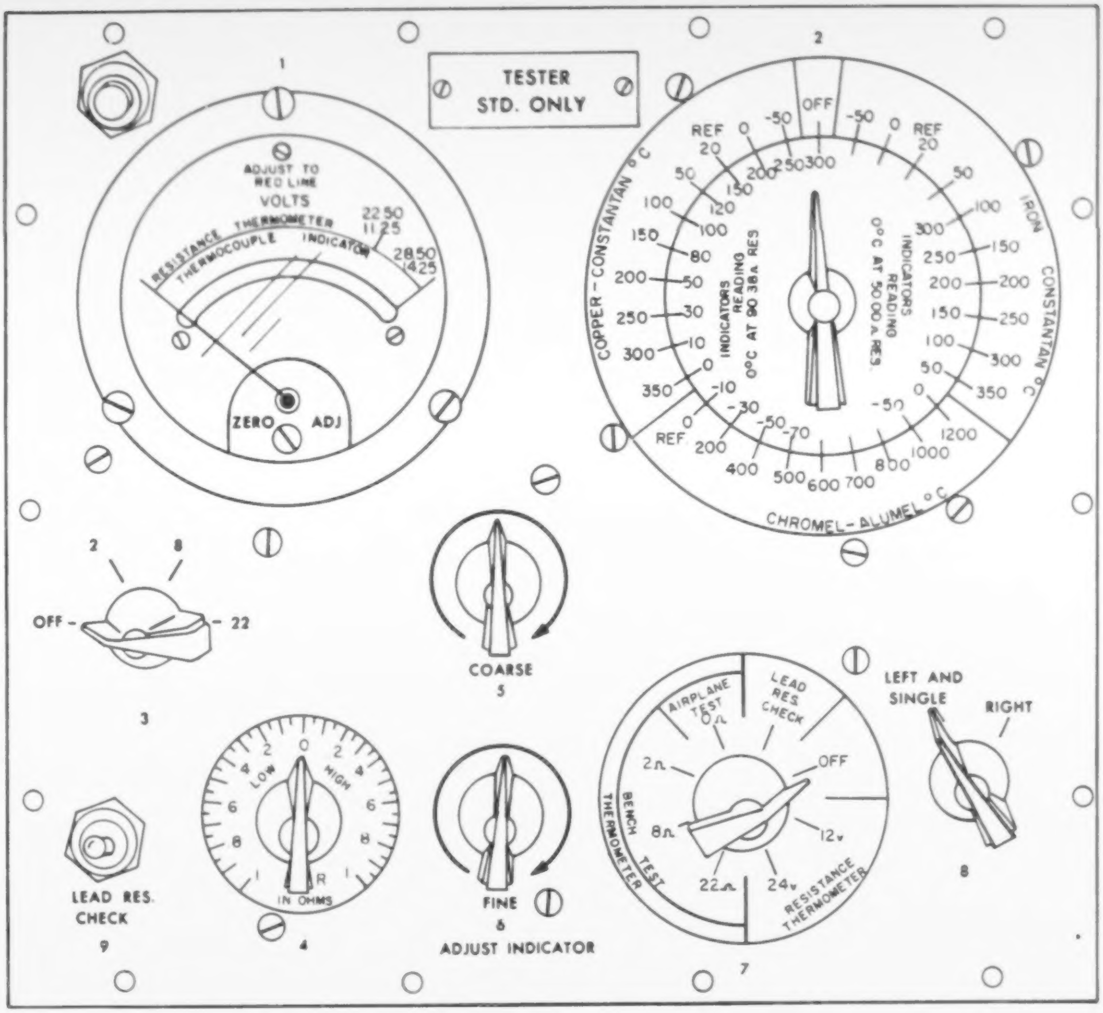

TESTER
STD. ONLY
1
ADJUST TO
RED LINE
VOLTS
RESISTANCE THERMOMETER
THERMOCOUPLE INDICATOR
2250
1125
2850
1425
ZERO
ADJ
2
OFF
REF
0
-50
20
50
100
150
200
250
300
350
120
80
30
10
-10
-30
-50
-70
400
500
600
700
800
1000
1200
COPPER - CONSTANTAN °C
IRON CONSTANTAN °C
CHROMEL-ALUMEL °C
INDICATORS READING 0°C AT 90.38Ω RES
INDICATORS READING 0°C AT 50.00Ω RES.
2
8
OFF
22
3
COARSE
5
LOW
HIGH
0
2
4
6
8
1
R
IN OHMS
4
LEAD RES.
CHECK
9
FINE
6
ADJUST INDICATOR
AIRPLANE TEST
LEAD RES. CHECK
0Ω
2Ω
8Ω
22Ω
OFF
12v
24v
BENCH THERMOMETER TEST
RESISTANCE THERMOMETER
7
LEFT AND
SINGLE
RIGHT
8

Figure 5–13. N–3A thermometer tester.

inside the tester cover for indicating ambient temperature. Notice the pushdown switch in the upper corner of figure 5-13. This switch is depressed by the tester cover to open the battery circuit when the tester is not in use.

The measurement meter (1) is used as an indicator for standardizing measurements and checking the condition of the batteries. The temperature selector switch (2) is a 30-position switch used to select the various calibration points when checking the calibration of the indicators. The outer portion of the dial is used for checking thermocouple thermometer indicators. It is divided into three colored sections. The yellow section is used to check iron-constantan indicators. The green section is used to check chromel-alumel indicators. The red section is used to check copper-constantan indicators. A lead resistance selector switch (3) is used to select the desired resistance when testing thermocouple circuit resistance on the aircraft.

A resistance control (4) is used for balancing the tester bridge circuit when checking circuit resistance. Balancing is indicated on the measurement meter. The control has a scale to show the error in resistance from −1 ohm to +1 ohm. The coarse and fine controls (5 and 6) are used for adjustment of the measurement meter when checking indicators. An 8-position resistance and voltage selector switch (7) is used to connect either 2.00 ± .05 ohms, 8.0 ± .05 ohms, or 22.0 ± .05 ohms in series with the indicator under test. The 0-ohm position provides a means for checking the indicator and thermocouple circuit on the aircraft. The lead resistance check position is used to check thermocouple circuit resistance on the aircraft. Switch (8) is used to check either single or dual indicators.

The lead resistance check switch (9) protects the measurement meter during severe circuit unbalances when you are measuring circuit resistance. The remaining parts of the tester are discussed later in this chapter under resistance thermometers. As you see, the N–3A tester can be used to check all components and circuits of the thermocouple system. However, it cannot be used to simulate actual engine-run conditions. The N-3A tester applies millivolts based on 0° C. The N°3A tester will cause the indicator to read high by the amount ambient temperature is above 0° C. The Jetcal tester is used to simulate actual engine run conditions.

Jetcal tester. The Jetcal tester simulates actual engine-run conditions by heating the probes to actual engine-run temperatures throughout the operating range. There are several styles of Jetcal heater probes. Each is made to fit over a particular type of thermocouple and each has its own part number. Do not mix the different types.

The thermocouples are heated simultaneously and stabilized at various temperature test points. The reading of the EGT indicator is then compared to that of the Jetcal tester. The Jetcal tester probes have their own thermocouples, the output of which is fed into a bridge circuit and balanced by a potentiometer adjustment. Of the three types of Jetcal testers currently used, the BH112 indicates this balanced condition by using a galvonometer. The accuracy of the reading should be within ± 4(de C. The Jetcal model H119 uses the same galvanometer principle, but a servomotor positions digital counter wheels to display the actual temperature applied to the thermocouples. The BH112JB-40 Jetcal analyzer also displays the actual temperature applied by using light emitting diodes (LEDs) to give a digital readout.

Before making the above system check, follow the Jetcal tester preparatory procedures to insure accuracy. The mechanical and electrical balancing of the galvanometer, for example, if not accomplished, would result in a false indication of temperature. With more than one thermocouple in a system, the chance exists that one may be faulty. Check each one by placing a hot probe over it and checking for a temperature rise on the indicator. You can also check the average output of all the engine thermocouples. You do this with a switch that allows all of the thermocouple outputs to be fed into the tester bridge circuit. The Jetcal tester accuracy in this type of test is ± 1° C. The Jetcal tester uses an external power supply of 115 volts. The BH112 models will operate on 50- to 400-Hz power. The H119 operates on 400 Hz only. A voltage controller (or probe control) allows the heater probe power to be varied and stabilized.

Provisions of each of these different Jetcal testers also permit you to check the lead resistance of a thermocouple circuit and measure the insulation breakdown of the leads. The H119 and BH112JB-40 models also include provisions which allow you to monitor engine RPM and engine pressures, as well as temperature, while the engine is running. Just from the brief description given, you can see how valuable and versatile the Jetcal tester is.

By studying the applicable TOs, you can acquaint yourself with the many features of the equipment. Good design and commonsense procedures, coupled with experience, make learning to use it a relatively easy and interesting task. The Jetcal tester can test and calibrate indicators, check resistance, insulation, thermal switches, and the rpm of the engine.

Those organizations operating jet aircraft depend upon the Jetcal tester as the standard for checking the accuracy of the EGT indicators and tachometers. It is used to troubleshoot systems when operational checks indicate inaccuracies. The rpm test is in itself a crosscheck because the rpm and the temperature of jet engines have a definite relationship. With one compact, portable tester, the mechanic can accomplish operations that might have taken as many as six testers before.

Procedures for balancing and setting the Jetcal tester in operation are conveniently located inside the cover of the tester. This information, combined with the informational TOs for the tester and the aircraft, will adequately cover all of the checks, troubleshooting, connections, and tolerances needed.

Stabilizing temperatures at test points, especially on cold, windy days, will be aided by the use of tail-cone covers. The temperature of the probes should never be allowed to exceed 900° C. The balance of the galvanometers should always be checked when readings are in error. This will preclude any test error from being introduced into the system.

Exercises (651):

1. Match the components the N-3A tester listed in column A with their functions and descriptions listed in column B. Write the correct letter in the space provided. Some functions/descriptions are used more than once and some are not used.

Column A

Components

_____ (1) Measurement meter.
_____ (2) Temperature selector switch.
_____ (3) Lead resistance selector switch.
_____ (4) Resistance control.
_____ (5) Coarse control knob.
_____ (6) Fine control knob.
_____ (7) Voltage selector switch.
_____ (8) Switch (8).
_____ (9) Lead resistance switch.

Column B

Functions/ Descriptions

a. Provides the means for reading the correct output of a thermocouple that is being heated.
b. Connects different resistance values in series with indicators under test.
c. Indicator for standardizing measurements.
d. Used to balance tester bridge circuit.
e. Provides the means for determining the correct polarity of a set of leads.
f. Checks condition of tester batteries.
g. Provides a means for checking thermocouple circuit resistance on the aircraft.
h. Adjustment for the measurement meter.
i. Divided into three colored sections for different type indicators.
j. Shows a resistance error −1 ohm to +1 ohm.
k. Provides a means for checking indicators and thermocouples on the aircraft.
l. Selects different calibration points.
m. Provides a means for checking single or dual indicators.
n. Selects the desired resistance for checking circuit resistance on the aircraft.
o. Protects the measurement meter against severe circuit unbalance.

2. How does a Jetcal tester simulate actual temperature conditions?

3. The point of balance is indicated on the BH112 Jetcal tester by a ________ .

4. The point of balance is indicated on the BH112 Jetcal tester by a ________ .

5. What type of external power does each of the Jetcal testers require?

6. What does the Jetcal testers have the ability to do?

7. What is the maximum temperature that may be applied to the Jetcal probes?

652. Specify test procedures and checks of the EGT systems.

Testing Thermocouple Systems. Two people, one in the cockpit and one at the engine, can easily check the exhaust gas temperature indicating system. Tests include:

a. EGT indicator accuracy check and adjustment.
b. Circuit insulation resistance check.
c. Circuit resistance check using the Jetcal tester.
d. Circuit resistance check using the Wheatstone bridge.
e. Thermocouple response check.
f. System accuracy check.

You should do each of the other checks before performing a system accuracy check. For those testers which have a self-check capability, you should do this check before using the tester. For example, on the H119, turn the TEMP switch to the CAL 600 position. The TEMP indicator should read 600° C. If it doesn't, you can adjust it to do so by using the CAL ADJUST potentiometer.

Indicator accuracy check. The first step in actually checking an EGT system is to verify the accuracy of the indicator. To do so, you must remove it from the instrument panel and use the indicator check adapter cable to connect it to the Jetcal tester. Place the resistance selector switch in the 4.21, 8, 15, or 22 OHM position for the type of system you are checking. Set the function selector switch to the A/C IND CHECK position, and set the TEMP switch to OPERATE. Start the indicator check with the A/C IND ADJ control fully counterclockwise. Turn the control clockwise until the pointer of the aircraft indicator moves upscale to the desired test point (usually 600°). Hold the indicator being checked in its normal operating position. The difference between the Jetcal TEMP indicator and the indicator under test is the amount of error. It should not exceed 5°. If it is out of tolerance, repair, adjust, or replace the indicator. Gently tap the indicator during adjustment and check. Using the adjustment on the back of the indicator, adjust it until it agrees with the Jetcal TEMP indicator. Then, disconnect the indicator from the tester; but, before reinstalling it in the instrument panel, perform the insulation resistance check and circuit resistance check.

CAUTION: Anytime the EGT indicator is disconnected, short together the terminals to provide meter damping.

Insulation resistance check using the Jetcal tester. To do this check, you must use the INSTRUMENT CABLE and the insulation check adapter with the Jetcal tester. Connect one lead of the insulation check adapter to one of the aircraft leads. Connect the other adapter lead to a good ground. Place the function selector switch to INSUL position and place the INSUL CHECK SWITCH to R (ohms) × 100. Normally, the required insulation resistance should be in excess of 2,000 ohms, but this varies with the type of aircraft. Check your TO to be sure.

NOTE: Some thermocouple probes and harnesses may absorb moisture under humid atmospheric conditions, causing less than desired insulation resistance. If it is less than allowed, either run the engine enough to dry out the probes and harness or heat the probes with the Jetcal thermocouple heaters at 600° to 700° for 20 to 30 minutes. Then repeat the resistance check.

After checking the lead, turn the function selector switch to OFF and move the insulation check adapter to the other lead. Next, do the circuit resistance check.

Circuit resistance Check. This check must also be accomplished with the aircraft indicator removed from the panel. Use the resistance check adapter and instrument cable with the Jetcal tester. Connect the resistance check adapter to the aircraft wiring leads. The copper (positive) lead will be red in color and will have the larger terminal center. The constantan (negative) lead will be yellow. The engine thermocouples must be at ambient temperature before you check resistance of the thermocouple circuit. Place the resistance selector switch to the correct OHM position, and set the function selector switch to RES position. The resistance meter should balance within (+-0.1 ohm. Check your TO to verify the tolerance.

CAUTION: At sometime in the past, the resistance spool was properly adjusted. So check, clean, and secure (tighten) all connections in the EGT system before adjusting the resistance spool.

If the resistance is not within tolerance and all wiring is found to be good, use a Wheatstone bridge to verify the circuit resistance.

Checking the circuit resistance using a wheatstone bridge. The Wheatstone bridge (fig. 5-14) is a readily portable instrument, weighing approximately 8 pounds, designed to measure resistances precisely. It is a self-

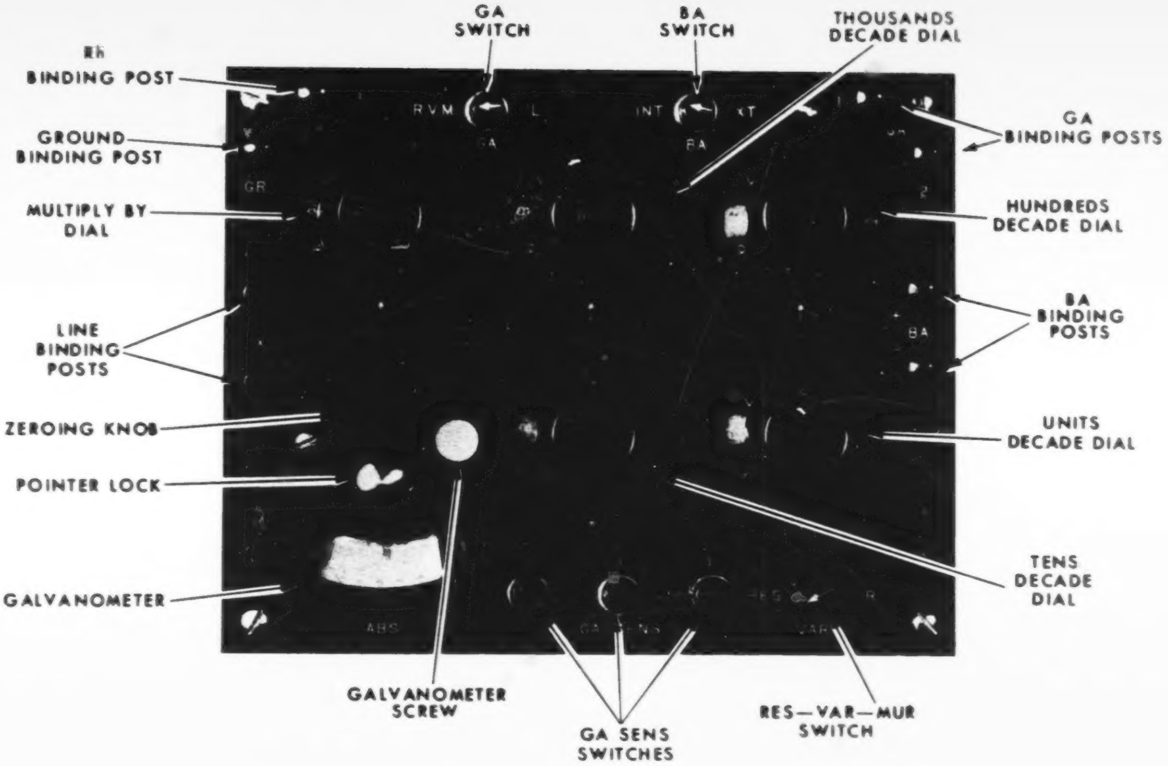

Rh BINDING POST
GA SWITCH
BA SWITCH
THOUSANDS DECADE DIAL
GROUND BINDING POST
GA BINDING POSTS
MULTIPLY BY DIAL
HUNDREDS DECADE DIAL
LINE BINDING POSTS
BA BINDING POSTS
ZEROING KNOB
UNITS DECADE DIAL
POINTER LOCK
TENS DECADE DIAL
GALVANOMETER
GALVANOMETER SCREW
GA SENS SWITCHES
RES—VAR—MUR SWITCH
RVM
GA
INT
XT
BA
GR
ABS
VAR

Figure 5–14. Wheatstone bridge.

contained, battery-operated instrument which uses a series of four rheostats and a galvanometer in a bridge circuit.

In order to accurately measure a resistance, first unlock the galvanometer and balance it at zero on the scale. Use TO 33A1–12–15–21 or the instructions in the lid to do this. Connect the resistance to be measured to the terminals X1 and X2. Set the MULTIPLY BY dial to the proper value as indicated in the following table:

Unknown Resistance			*MULTIPLY BY Dial Setting*
	Below 10		ohms.........1/1000
10	ohms to	100	".............1/100
100	" "	1000	".............1/10
1000	" "	10000	".............1/1
10000	" "	100000	".............10/1
100000	" "	1000000	".............100/1
1000000	" "	10000000	".............1000/1

Balance the bridge by adjusting the four rheostats (1, 10, 100, and 1000) until the galvanometer does not deflect when the sensitivity keys are depressed. Then the unknown resistance (in ohms) is equal to the sum of the rheostat dial settings multiplied by the setting of the MULTIPLY BY dial. If the resistance is still out of tolerance, you will have to adjust the resistance spool. Remember, you can only remove wire from the spool. You cannot add wire to it. If the resistance is too low, you must use the spare spool or replace the spool.

Thermocouple response check. This next check can be done with the aircraft indicator installed or removed. Let's examine the procedures with the indicator removed from the instrument panel. Connect the CHECK cable to its receptacle on the Jetcal tester. Connect the other end of the CHECK cable to the engine thermocouple harness connector. Connect the HEATER cable to its receptacle on the Jetcal tester and to the continuity check probe. This is the one-of-a-kind thermocouple heater used with the Jetcal tester. If the continuity check probe is not available, use the junction box and one heater probe assembly of the proper type to fit the installed thermocouples.

Place the functionn selector switch to the TRIM–T/C positio and the TEMP INPUT switch to the OPERATE position. Adjust the temperature control to 100 percent. When the temperature stabilizes (approximately 700° C), hold the TEMP INPUT switch in the CHECK CABLE position. An extra person may be required to do this. Apply the hot heater probe to each thermocouple in turn (one at a time). When a rise in temperature is seen on the TEMP indicator of the Jetcal, remove the hot probe and allow the TEMP indicator to stabilize, and then move to the next thermocouple. Check all thermocouples in this manner. A thermocouple that does not give a rise in temperature indication is probably defective and should be replaced and rechecked. If there is still no rise, the thermocouple harness is defective.

System accuracy check. You are finally ready to check the accuracy of the complete system as the specialist in figure 5-15 is preparing to do. Remove the indicator from the instrument panel and disconnect the leads. Connect the EGT indicator to the switch box, using the leads marked EGT INDICATOR. These are accessories furnished with the Jetcal tester. Set switch SW–5 on the switch box to JETCAL. Connect the airplane EGT leads to the switch box terminals marked AIRCRAFT TC LEADS, and connect the CHECK CABLE between the switch box and Jetcal tester. Connect the HEATER CABLE to the junction box and to the Jetcal tester. Connect one heater probe to the junction box for each thermocouple in the aircraft system. If there are six thermocouples, use six heater probes. Only heater probe assemblies with identical part numbers and heater probe cables of equal length can be combined to perform this check. To avoid erratic indications due to high winds or cold weather, cover the intake and the exhaust of the engine during the test. Place one heater probe over each thermocouple installed on the engine. Probes must be pushed completely on the thermocouples.

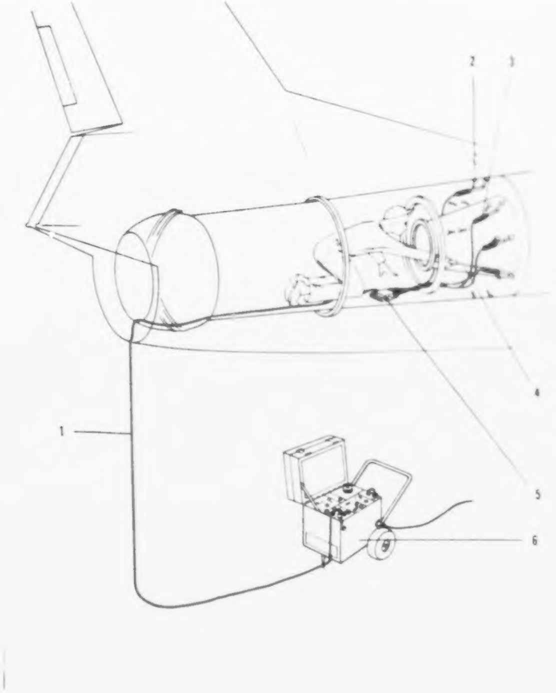


Figure 5–15. Preparing to do an EGT system accuracy check using a jetcal analyzer.

Place the function selector switch to the TRIM–T/C position. Place the TEMP INPUT switch to HEATER CABLE and place the TEMP switch to OPERATE.

Adjust the TEMP control to achieve a Jetcal TEMP indicator reading of 600° C. Allow the heater probes to "soak" on the thermocouples for at least 10 minutes at the selected temperature. The time it takes to heat and stabilize the temperature depends upon the line voltage, ambient temperature, and air currents. Some engines, after being idle for some time, collect moisture on the thermocouples and terminals. Extra time has to be allowed for this moisture to evaporate. If, after 10 minutes, the system is not within limits, you may let it soak an additional 20 minutes. If it is still out of tolerance, the difference will be system error.

Record the stabilized Jetcal TEMP indicator reading. Hold the TEMP INPUT switch to CHECK and record this TEMP indicator reading. These two readings must be within 8° of each other. Place switch SW–5 on the switch box to the EGT position. This allows the thermocouple temperature to be read on the aircraft EGT indicator. The EGT indicator must agree within 10° of the reading of the Jetcal TEMP indicator. If it does, that completes your check of the system. Turn the TEMP control to zero and the function selector switch to OFF. Disconnect your equipment and reinstall the EGT indicator. Use extreme caution when handling the hot thermocouple heater probes.

Exercises (652):

1. List the checks that should be done before performing an EGT system accuracy check.

2. What is the purpose of the CAL 600 position of the TEMP switch on Jetcal testers?

3. The EGT indicator accuracy check is started with the A/C IND ADJ control in what position?

4. How do you connect the insulation check adapter to the EGT system to do an insulation resistance check?

5. How is the resistance check adapter connected to the aircraft EGT circuit?

6. What two things should you do before adjusting a resistance spool?

7. When using a Wheatstone bridge, what indicates the value of the unknown resistance?

8. What is the purpose of the thermocouple response check?

9. What is the purpose of the junction box when it is used in performing a system accuracy check?

10. What is the purpose of the switch box?

5-3. Resistance Thermometer Systems

Resistance thermometers operate on voltages of 12- or 24- volts DC supplied by the aircraft power system. If the aircraft uses a 12-volt system, the voltage applied to the resistance thermometer will vary between 12 and 14 volts. On a 24-volt system, it will vary between 24 and 28.5 volts. One of the major advantages of this temperature-measuring device is that it will operate correctly even though the voltage varies slightly.

653. Specify the operational characteristics of the resistance thermometer system.

This system consists of an indicator, a resistance bulb, and the necessary wiring. The indicator is mounted on the instrument panel, and it may be either the single or dual type. The bulb is mounted at the point where the temperature is to be measured.

Resistance Bulbs. Resistance bulbs are used in the many different thermometer systems. They will appear in a variety of sizes and shapes. Although they look different physically, they are identical electrically. A short bulb is used to measure the temperature of oil, coolant, and carburetor air. It is interchangeable with a longer bulb. In most cases, however, the long bulb cannot be used in place of the short one. This is purely because its length won't allow it to fit in the same places. A disk-shaped bulb is used to measure free air temperature. It cannot substitute for either of the other two bulbs. This bulb is constructed to fit flush with the skin of the aircraft so that it will offer no resistance to the airflow around the aircraft.

There are basic working elements of a resistance bulb. If the bulb were divided into sections, the three main sections would probably be the stem, the body, and the electrical connector. Each section contains certain elements that help make up the bulb.

The stem contains silver heat conductors, which are used to conduct heat to the nickel winding. This winding is made of wire, very small in diameter, wrapped around a pice of mica insulation. Nickel is used because its resistance in electrical circuits is greatly affected by changes in the temperature. The winding extends from the base of the stem back to the two pins in the electrical connector.

When voltage is applied to the pins in the connector, current flows through the nickel winding. Since the voltage is constant, the amount of current flow will be controlled by the resistance of the winding.

Indicators. Resistance thermometer systems can use either one or two bulbs. A single bulb is connected to a single indicator, or two bulbs are connected to a dual indicator. The range of the indicator is determined by the temperature range of the function being measured. Although there are indicat that have different temperature ranges, one that is universally used has a range between −70° and +150° C. When this indicator is used, an identification plate or decal must be installed to indicate the source of the temperature being measured. When the indicator is used in 12-volt systems, it allows current to bypass the dropping resistor. The resistance thermometer indicator contains a ratiometer movement and a modified bridge circuit. First, we are going to determine how the bridge circuit works and how it provides temperature indications. Then we shall discuss why the ratiometer is needed and how it operates.

An elementary fixed-bridge circuit and the D'Arsonval movement are shown in figure 5-16, detail A. The resistors R1, R2, R3, and R4 are inside the indicator; and resistor R5, which is variable, is connected to the indicator. The flow of current across the indicator movement depends upon the balance of the bridge circuit. When R5 is of low value, more current passes through R5, R3, and R2, crossing through the meter movement from a to b. When R5 is of high value, more current passes through R4, R3, and

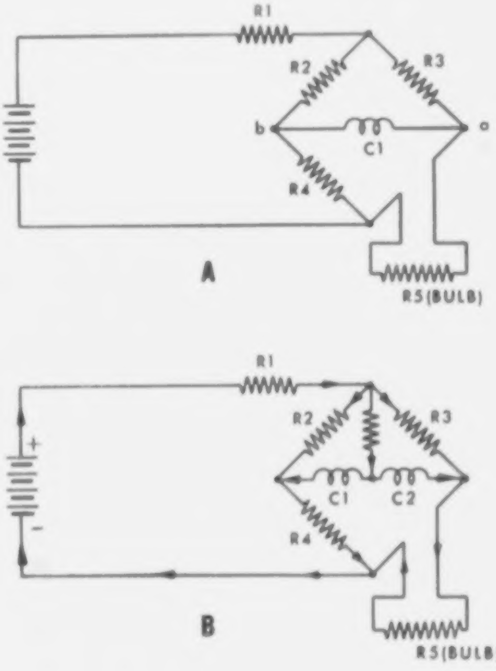


Figure 5-16. Basic resistance thermometer circuits.

R2, crossing the meter movement from b to a. The resistor (R5) is the resistance bulb installed where it is necessary to measure the temperature. The indicator dial is calibrated in degrees of temperature.

Let us assume that the voltage supply varies. If the voltage drops and the resistance remains constant, the indicator would indicate a lower temperature, even though no temperature change has occurred. This deflection of the movement is a function of current flow. The ratiometer movement was developed to overcome this unwanted indication. Actually, the ratiometer movement is very similar to the D'Arsonval movement, except that it uses two coils instead of one. The deflection of the pointer here depends upon the ratio of current flow in both coils. Study figure 5-16. Notice that C1 and C2, in detail B, have the same function as C1, detail A.

Now, as power supply voltage varies, current flow in both coils will change equally. Since the deflection is a ratio of current flow in both coils, no pointer movement will result. The resistance bulb (R5) has the same effect as before. The change in current flow is in two coils instead of just one coil.

Another method that is used is shown in figure 5-17. Instead of having a double-coil moving element, coils A and B are stationary. A permanent magnet moves as the fields of the coils change value. Electrically it is the same as the previous example, but it has the advantage of eliminating the hairsprings. However, a small permanent magnet is added to draw the pointer off the scale when not in operation. The hairsprings accomplish this function in the other movements. Because the resistance of the bulb directly controls the current flow in the coils and, consequently, the indicated temperature, its resistance must be accurate.

Exercises (653):

1. What are the short resistance bulbs normally used for?

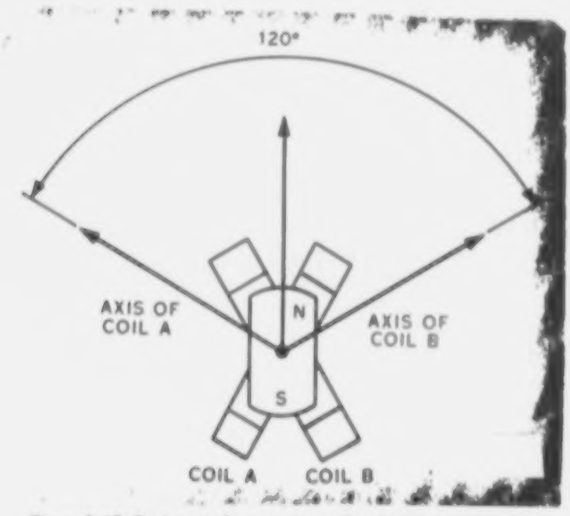


Figure 5-17. Resistance thermometer coil and magnet arrangement.

2. Describe three typical resistance temperature bulbs.

3. Which type of resistance temp bulb cannot be substituted for the other two? Why?

4. What is the sensing element used in a resistance bulb? Why?

5. What is the purpose of the dropping resistor used in resistance thermometers?

6. Why was the ratiometer movement developed?

7. Describe the difference between the D'Arsonval movement and the ratiometer movement.

8. In the ratiometer movement, what is the advantage of making the coils stationary rather than movable?

645. State resistance thermometer indicating system inspection and operational check procedures, and identify the probable causes of resistance thermometer troubles.

Inspection. Inspection requirements for the system include checking the indicator for security of mounting, condition of the cover glass, and proper placement of range markings. Check the resistance bulb for security of mounting, obvious damage, and proper safetying. As with all electrically connected systems, you check the condition of the wiring and the electrical connectors.

Operational Check. Operational checks on resistance thermometer systems are quite easily performed. You simply apply power to the system and check to insure that the temperature indications are consistent with known temperatures.

Troubleshooting. Troubleshooting the system is rather easy. Troubles in the bridge circuit give definite indications. When the bulb circuit opens, the indicator will read off-scale hot. If a short circuit occurs, it will read off-scale cold. Errors of temperature that are higher or lower than the known temperature are the result of the indicator's being out of calibration, of incorrect bulb resistance, or poor lead connections. Since most aircraft use several ratiometers, the interchanging of indicator leads is a quick check used by many mechanics. All of the ratiometers that have been discussed thus far use the bulbs having a resistance of 90.38 ohms at 0° C. There is another type of bulb that is used for obtaining cylinder-head temperature. It is impossible, however, to interchange it with any of the other resistance bulbs. There are leads attached to the bulb. The resistance is 50 ohms at 0° C. But the system is identical to others in all other respects.

The decade box is one of the best troubleshooting aids for the resistance thermometer systems. The decade box contains a set of variable resistors connected in series. Five knobs are used to control the resistance from 0 to 11,111 ohms. The resistors are enclosed within the box. A set of leads connect the box to the system.

You must consult the applicable TO for the scale error test point and resistance values. As an example, set the decade box controls to the specified bulb resistance. The indicator should show the temperature corresponding to that resistance.

Test Equipment. The N-3A tester, shown in figure 5-13, is used to check the calibration of resistance-type thermometers in the shop. Notice that switch 2 has an inner dial. This dial has the test points for checking resistance thermometers. The left scale is for checking indicators using resistance bulbs having 90.30 ohms at 0° C. Meter 1 (fig. 5-13) has a scale for resistance thermometers (top scale). The scale has increments marked "22.50 or 11.25 volts, and 28.50 or 14.25 volts." The 22.50- to 28.50-volt range is used when checking 24-volt indicators. The 11.25- to 14.25-volt range is used when checking 12-volt indicators. The voltage of the indicator being checked is selected by switch 7 (12 or 24 volts). Both single and dual indicators can be checked by positioning switch 8.

Bench Check. For our example of a bench check, let's check a type G-10 resistance thermometer. We will use the N-3A tester for this check. The indicator is a single indicator which operates from 28.50-volts DC. It has a range from −70° C. to +50° C. The indicator is used with bulbs having 90.38-ohm resistance at 0° C. Refer to figure 5-13 as we discuss the following procedures:

(1) Mount the indicator in a position such as would normally occupy in the aircraft.

(2) Connect the indicator to the tester, using the proper test cable. The cables are supplied with the tester.

(3) Position switch 8 for the type of indicator being tested (dual or single). In this case, switch 8 would be placed to LEFT and SINGLE.

(4) Position switch 2 to the proper scale for the ohmic value of the resistance bulb used with the indicator. For this indicator, you would place switch 2 to 0° C. on the 90.38-ohm scale.

(5) Position switch 7 for the proper voltage input to the indicator—in this case, 24 volts.

(6) Adjust Rheostats 5 and 6 to cause meter 1 to indicate 28.50 volts. This adjustment insures that the proper voltage is applied to the indicator and tester circuits.

(7) Position switch 2 to each of the test temperatures, as indicated in the applicable TO. Take indicator readings at each of the test positions. (NOTE: Lightly finger-tap the indicator before each reading is taken.)

(8) If the readings obtained in step 6 are correct with meter 1 adjusted to 28.50 volts, lower the voltage to 22.50 volts on meter 1 by adjusting rheostats 5 and 6.

(9) Take another set of readings throughout the indicator range. The readings obtained with 22.50 volts applied may vary from the readings taken in step 6. Variation tolerances are listed in the applicable indicator TO.

(10) Upon completion of the test, turn off all tester switches and disconnect the indicator from the tester.

If the indicator meets the TO specifications, it is ready for use. If not, it must be calibrated in accordance with the procedures outlined in the applicable TO.

Exercises (654):

1. State the inspection requirements for the bulb in the resistance-type thermometer system.

2. State how you perform an operational check of the resistance thermometer system.

3. Match the hypothetical malfunctions in the resistance thermometer listed in column A with their probable causes listed in column B. Write the correct number in the space provided. Some probable causes are used more than once.

Column A *Hypothetical Malfunction*		*Column B* *Probable Cause*
____ (1) Off-scale indication.	hot	a. Indicator out of calibration.
____ (2) Off-scale indication.	cold	b. Defective indicator.
____ (3) Low indication.		c. Open lead.
____ (4) High indication.		d. Poor lead connections.
		e. Defective bulb.
		f. Incorrect bulb.
		g. Lead shorted to ground.

4. What types of resistance thermometer system indicators can be checked with the N-3A tester?

5. When bench-checking resistance thermometer system indicators, where can you find the list of test temperatures used to check the indicators?

6. Assume the wing commander requested a job be dispatched to the instrument shop to install an outside air temperature gage in the office in the cargo compartment of his or her assigned aircraft. He or she wanted it wired in parallel with the copilot's outside air temperature indicator. Would both gages indicate properly? If not, explain why.

Vertical Scale Engine Instrument Systems

THE VERTICAL SCALE engine instrument systems provide the pilot and flight engineer with indications of engine pressure ratio (EPR), speed of the engine dual compressors (N1, N2 rpm), exhaust gas temperature (EGT), and rate of fuel flow. These tape-type instruments present the same information to the pilot and flight engineer as do the dial type instruments. However, the tape-type instruments have two distinct advantages over the dial type. They take up less space and are easier for the pilot and flight engineer to read at a glance.

In the following paragraphs we are going to discuss the construction of the vertical scale engine instrument system components. After discussing the component construction, we are going to tie the components together to form each of the individual indicating systems. Then we will give a description of the system operation for each indicating system.

Because you may be responsible for maintaining the vertical scale engine instrument systems, we will discuss troubleshooting and the test equipment that is used to check the systems. To properly maintain the vertical-scale engine instruments, you must have a thorough knowledge of the systems. So let's begin our discussion with a description of the components of each system.

6-1. System Components

The vertical scale engine instrument systems consist of the engine-mounted signal-producing components, the converter units, and the indicators. The signal-producing components are the tachometer generators, thermocouples, fuel flow transmitters, and engine pressure ratio transducers. Each engine has a complete set of signal-producing components. They are mounted on or near the engine about which they are sensing information. Since system operation begins with the signals produced by the signal-sensing components, let's discuss them first.

655. State the number of tachometer generators mounted on an engine with vertical-scale instruments and the type of voltage produced by these tachometer generators.

Tachometer Generator. Two tachometer generators are used on each engine. The reason is that the aircraft in which the vertical-scale engine instruments are installed use engines with dual axial compressors. The dual compressors in these engines are mechanically independent of each other. Since the compressors are mechanically independent, it is possible for them to turn at different speeds. Therefore, it is necessary to have an rpm indicating system for each compressor. One rpm indicating system shows the speed of the forward (low-speed) compressor. This is referred to as the N1 rpm indicating system. The second rpm indicating system indicates the speed of the aft (high- speed) compressor. This is referred to as the N2 rpm indicating system.

The tachometer generator most commonly used with the vertical scale rpm indicating systems is the type GEU/7A miniature generator. The generator contains a two-pole permanent magnet rotor and a 3-phase stator. Except for its smaller size, the generator is identical to the tachometer generator you studied earlier in this volume. The generator produces 3-phase AC voltage. The amount of voltage and frequency produced by the generator depends upon the rpm of the rotor.

Exercises (655):

1. State how many tachometer generators are mounted on each engine of the aircraft that have vertical scale engine instruments. Why?

2. Cite the type voltage produced by the tachometer generators of the vertical scale engine instrument system.

656. Complete given statements concerning thermocouple construction and their output and compare the construction and appearance of the vertical scale engine instrument thermocouple to the dual thermocouple.

EGT Thermocouple. The EGT thermocouple probes are identical in construction and similar in appearance to the dual thermocouple probes you studied earlier in this volume. Each of the probes contain two chromel-alumel thermocouples. Six probes are mounted around the turbine exhaust case of each engine, where they are exposed to the exhaust gases. The thermocouples of each probe are connected in parallel. The thermocouples produce a DC-millivolt signal which is proportional to the average exhaust gas temperature.

Exercises (656):

1. The thermocouples that are used with the vertical-scale engine instrument system are made from ________ ________ .

2. What type of signal is produced by the thermocouples?

3. How do the vertical scale engine instrument thermocouple construction and appearance compare with the construction and appearance of the dual thermocouple?

657. Cite operating characteristics of the vertical-scale engine instrument fuel flow transmitter.

Fuel Flow Transmitter. The fuel transmitter (XMTR) differs somewhat from the common synchro fuel flow XMTR that you studied earlier in this volume. However, the signal output to the fuel flow indicating system is the same. The XMTR provides a synchro signal output to the system. The angular position of the synchro rotor is directly proportional to the mass rate of fuel flow. The signal is applied directly to the indicator.

Like the second-harmonics XMTR, this XMTR operates on the principle that the amount of fluid flow can be measured by its resistance to deflection. The XMTR receives 115-volt, 400-Hz, single-phase, AC power from the converter unit (discussed later). This AC power is supplied to a motor in the transmitter. The motor drives an impeller at a constant 60 rpm. As fuel flows into the XMTR through the inlet vane, the impeller causes the fuel to swirl. The torque created by the swirling fuel causes the inlet vane to be moved against a restraining spring. When the torque applied to the vane equals the resistance of the inlet vane restraining spring, the vane movement stops. The movement of the inlet vane, through a magnetic coupling, positions the rotor of the synchro unit.

Exercises (657):

1. Cite the signal output provided to the vertical scale engine instrument system by the fuel flow transmitter.

2. Cite the type of power required to operate the impeller motor of the fuel flow transmitter.

658. Complete given statements concerning the signal-sensing device in the vertical scale EPR transducer and the difference in construction of the vertical scale and conventional EPR transducers.

EPR Transducer. The EPR transducer used in the vertical-scale engine instrument system is similar in construction and appearance to those you studied earlier in this volume.

The tube-type amplifier and discriminator are replaced by an amplifier and discriminator of the transistor type. The EPR signal is sensed by an inductive bridge circuit (E-core transformer) instead of a capacitive bridge circuit. Even though slight differences in the transducers are evident, the operating principle of the transducers is identical. The transducer provides a synchro signal output to the EPR indicator.

Exercises (658):

1. The signal-sensing circuit incorporated in the EPR transducer used with the vertical scale engine instrument system is an ______ ______ _______ .

2. What is the difference between the vertical scale and the conventional transducer?

6-2. Converter Unit

The converter unit is a shock-mounted, transistorized unit. It contains 16 channel boards. The channel boards contain the conversion circuitry and amplifiers necessary to operate the vertical scale indicating systems. Input signals to the channel boards are supplied by the tachometer generators, the EGT thermocouples, and fuel flow indicators. The signals from the EPR transducers are supplied directly to the indicators. They do not pass through the converter unit.

659. State the purpose and what determines the output of the rpm channel boards in the converter unit.

RPM Channels. The rpm channels receive variable N1 or N2 tachometer generator signals. Each channel contains the circuits necessary to convert the output of the generator to a DC signal. The voltage of this DC signal depends on the frequency output of the generator. The DC signal is then modulated to a 400-Hz AC signal, amplified and supplied to the rpm indicator servomotors. Eight identical rpm channel boards are used in the converter unit. The channel boards may be interchanged with each other.

Exercises (659):

1. State the purpose of the rpm channel boards in the converter unit.

2. What determines the DC output voltage of the rpm channel boards?

660. State the purpose of the vertical scale EGT boards.

EGT Channels. The EGT channels receive a DC-millivolt signal from the thermocouples. The channel boards contain the circuitry necessary to convert the DC-millivolt signal to a 400-Hz AC signal. The AC signal is amplified and supplied to the servomotors in the EGT indicators. Four identical and interchangeable EGT channel boards are located in the converter unit.

Exercises (660):

1. State the purpose of the EGT channel boards in the converter unit.

661. Cite the purpose of the vertical scale fuel flow channel boards.

Fuel Flow Channels. The fuel flow XMTR output signal bypasses the fuel flow channel and is supplied directly to the fuel flow indicator. The signal is received by a control transformer in the indicator. The error signal induced into the rotor of the control transformer is sent back to the converter unit. The error signal is received by the fuel flow channel board. The channel board contains the circuitry necessary to amplify and discriminate the error signal. The signal is then sent back to the indicator servomotor. Four fuel flow channel boards are used in the converter unit. These channel boards are also interchangeable with each other.

Exercises (661):

1. Cite the purpose of the fuel flow channel boards in the converter unit.

662. Cite the purpose of the fuses and connectors in the converter unit.

Fuses and Connectors. Sixteen fuses and 10 connectors are located on the front of the converter unit. The fuses are numbered F–1 through F–16. There is one fuse for each of the 16 channels of the converter unit. The fuse number and the circuit that it protects are printed on the top of the converter unit. The connectors, numbered J1 through J10 and provide a means for connecting the signalsensing components and the vertical scale indicators to the converter unit.

Exercises (662):

1. Cite the purpose of the fuses and connectors located on the converter unit.

6-3. Vertical Scale Indicators

Next we will discuss the description and purpose of vertical scale engine instrument indicators. A typical arrangement of the vertical scale engine indicators as they might appear on the instrument panel is shown in figure 6-1. Notice in figure 6-1 that the EPR indicators (B) for all four engines appear on four separate tapes inside one indicator. Except for the calibrated ranges, the rpm (C and D), EGT (E), and fuel flow indicators (F) appear identical to the EPR indicator. The vertical scale indicators are internally lighted. Two identical sets of the indicators are used in the vertical scale engine instrument systems. One set is mounted on the pilot's engine instrument panel, and the other set is mounted on the flight engineer's panel. The word "OFF" (A) appears at the top of the indicators when power is not applied to the system. Item (G) shows the movable tapes.

663. State the rpm that is indicated on N1 rpm indicator and the purpose of the variable potentiometers in the rpm indicators.

RPM Indicators. Notice in figure 6-1 that two rpm indicators are located on each panel. The rpm indicator labeled "N1" shows the speed of the engine's low-speed compressor. The rpm indicator labeled "N2" shows the speed of the engine's high-speed compressor. Each rpm indicator displays the rpm of four engines on four moving tapes. The tapes are read against a stationary scale. Each numbered increment on the scale is read as percent of RPM × 10. From zero to 90 percent of rpm, the scale is calibrated in 5-percent increments. From 90 to 110 percent of the rpm, the scale is calibrated in 1-percent increments.

The rpm indicator contains a servomotor and gear train for each indicating tape. A variable potentiometer, positioned by the gear train, is also incorporated for each tape. The variable potentiometer provides a servoloop rebalance voltage back to the rpm channel boards.

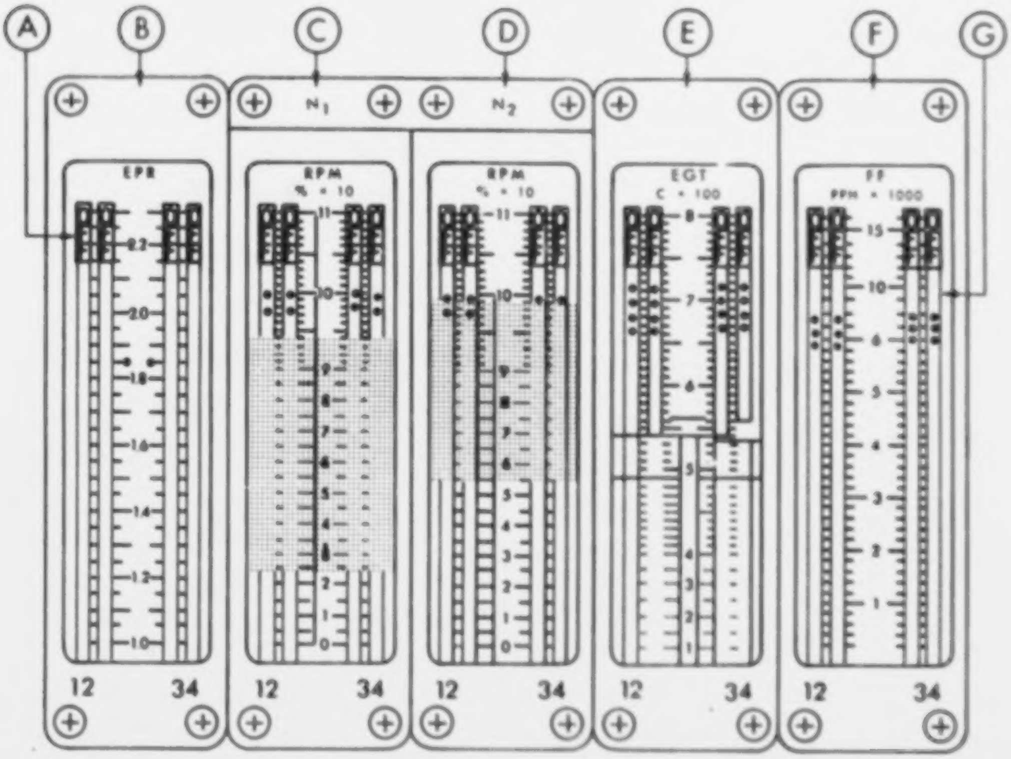
Exercises (663):

1. State the rpm that is indicated on the N1 rpm indicator.

2. State the purpose of the variable potentiometers in the rpm indicators.

664. Compare the vertical scale EGT and rpm indicators.

EGT Indicators. Except for the calibrated scale, the EGT indicators are constructed just like the rpm indicators. The EGT scale has a range from 100° to 800° C. From 100° to 400°) C., the scale is calibrated in 50°) increments. From 400° to 800° C., the scale is calibrated in 10° increments. Each numbered increment on the scale is read as degrees



A POWER OFF INDICATORS
B ENGINE PRESSURE RATIO INDICATOR
C TACHOMETER (RPM) INDICATOR (N_1)
D TACHOMETER (RPM) INDICATOR (N_2)
E EXHAUST GAS TEMPERATURE INDICATOR
F FUEL FLOW INDICATOR
G MOVABLE TAPES

Figure 6-1. Vertical-scale engine instruments.

EGT × 100. The increments are smaller at the high range because the temperture is more critical there.

Exercises (664):

1. Compare the vertical scale engine instrument EGT and rpm indicators.

665. State the major construction difference between the vertical scale fuel flow indicators and the rpm and EGT indicators.

Fuel Flow Indicators. The fuel flow indicator is constructed almost identically to the indicators we have discussed thus far. The major difference is that a control transformer is incorporated in each tape gear train to cancel the servoloop operation. This difference will be discused later. Each tape in the indicator shows the rate of fuel flow for its respective engine. The tape is read against a calibrated scale. The indicator has a range from 400 to 16,000 pounds per hour (PPH). Each numbered increment is read as PPH fuel flow × 1000. From 400 to 6,000 PPH, the scale is calibrated in 200-PPH increments. From 6,000 to 16,000 PPH, the scale is calibrated in 1,000-PPH increments.

Exercises (665):

1. What is the major construction difference between the fuel flow indicators and the rpm and EGT indicators?

666. Identify the component of the vertical-scale EPR indicators that makes it unnecessary for the signals to pass through the converter.

ERP Indicators. As you learned earlier, the EPR indicator contains the signal amplifiers of the indicating system servoloops. Therefore, the servoloops are contained within the indicator, making it unnecessary for the EPR signals to pass through the converter unit. The construction of the EPR indicator is slightly different from that of the indicators we have discussed up to this time. As you should recall, the signals from the EPR transducers are supplied directly to the EPR indicator. Consequently, the EPR indicator contains four complete servoloops, one servoloop for each indicating tape. Each servoloop consists of a control transformer, signal amplifier, discriminator, servomotor, and gear train. The gear train positions the tape and moves the rotor of the control transformer. This nulls out the signal from the EPR transducer.

The indicator has a range from 1.0 to 2.3 units of EPR. Each increment is equal to 0.05 units of EPR.

Exercises (666):

1. What the component found in the vertical scale EPR indicator makes it unnecessary for the EPR signals to pass through the converter unit?

6-4. System Operation

In the following paragraphs, we will discuss the operation of the rpm, EGT, fuel flow, and EPR system. Since each individual tape indicating system in each indicator operates the same, we will discuss only one individual tape system for each indicator.

667. Identify the function or description of given components of the vertical scale rpm indicating system.

RPM System Operation. Except for the routing of the tape inside the indicator, all of the eight rpm indicating tape systems are identical. Therefore, when we have completed our disucssion of one rpm tape indicating system, we will have effectively discussed all eight rpm systems.

From our description of the vertical-scale indicators, you should recall that, when no power is applied to the systems, the word "OFF" is in view at the top of the tapes. So let's use this point to begin our discussion. If the system circuit breakers are set, power is applied to the system when power is applied to the aircraft. The AC power is applied to the converter unit. Figure 6-2 is a block diagram of one rpm indicating system. Since this diagram shows fuse F3 in the converter unit, the circuit is identified as the number one engine N1 rpm indicating system.

In figure 6-2, the AC voltage passes through fuse F3 to the amplifier power supply of the rpm channel board. If you follow the wire connected to the right end of fuse F3, you will find that it is also connected to the pilot's and the flight engineer's indicators. The AC is used in the indicators for the servomotor fixed-phase reference voltage. The amplifier power supply furnishes the regulated DC voltages to the amplifiers. These voltages are also used to rebalance potentiometers (R1) in the indicators. The power supply also furnishes the AC reference voltage to the modulator circuits.

Notice in figure 6-2 that the DC output from the converter is supplied to both the pilot's and flight engineer's modulator circuits. The magnitude of the voltage depends upon the input frequency. From this point, the circuits are independent of each other. However, they operate the same. For this reason, we will discuss only the pilot's circuits.

When power is applied to the system and the engines are not running, a small DC output from the converter is supplied to the modulator circuits. The modulator circuits change the small DC signal to a small 400-Hz AC signal. The small AC signal is fed to an amplifier where the signal is boosted in strength. From the amplifier, the signal is fed to an amplifier clipper. Inside the clipper circuits, the alternation of the signal that is not needed is clipped. The clipped signal is then supplied to a push-pull amplifier circuit. Here the signal is amplified again and supplied to the control phase of the servomotor in the indicator, where it causes the servomotor to drive.

As the servomotor drives, a gear train positions the tape and the wiper of R1. The servomotor continues to drive until the DC rebalance voltage is felt on the wiper of R1. This is of sufficient strength to cancel the DC input from the converter to the modulator. At this time, the servomotor stops. The tape has moved up the indicator just far enough to remove the word "OFF" from view. The indicator now appears blank except for the calibrated scale.

The tape is mechanically positioned by the gear train and two tape drums. The tape threading route and the tape drums are shown in figure 6-3. When the gear train is turned by the servomotor, the tape drum rotates in the direction shown by the arrow on its side. The small tape takeup drum is turned at the same time in the direction shown by the arrow on its side. Now look again at figure 6-3 and follow the tape from the tape drum. It moves down under the bottom pulley, up across the indicator dial, over the top pulley, and onto the tape takeup drum. When the drums rotate, the tape is moved in the direction shown by the arrows near the tape. The word "OFF" is removed from view.

Now you are probably wondering what causes the tape to move back down the scale when power is removed from the system. Inside the tape drum housing is a spiral spring. One end of the spring is locked to the tape drum shaft. The other end is locked to the drum housing. When the drum is rotated by the gear train, the tension on the spiral spring is increased. When power fails to the system, the tension of the spiral spring causes the gear train and the tape drums to rotate in the opposite direction. The tape moves opposite the direction shown by the arrows in figure 6-3 until the word "OFF" appears at the top of the indicator.

Up to this point, we have discussed the operation of the system without the engines running. But suppose we apply power to the system. and the word "OFF" is removed from view on the indicator. Then, as the engine is started, the rotor of the tachometer generator starts to turn. Notice in figure 6-2 that a 3-phase AC voltage and frequency output, proportional to the generator rotor speed, is supplied to the push-pull amplifier. The push-pull amplifier boosts the generator output signal to a strength usable in the converter. This converter changes the AC signal from the push-pull amplifier to a DC signal. The magnitude of the DC signal increases as the frequency of the generator output increases. The DC signal is then fed to the pilot's and the flight engineer's modulator circuits. The modulator changes the DC signal to a 400-Hz AC signal of the proper phasing to

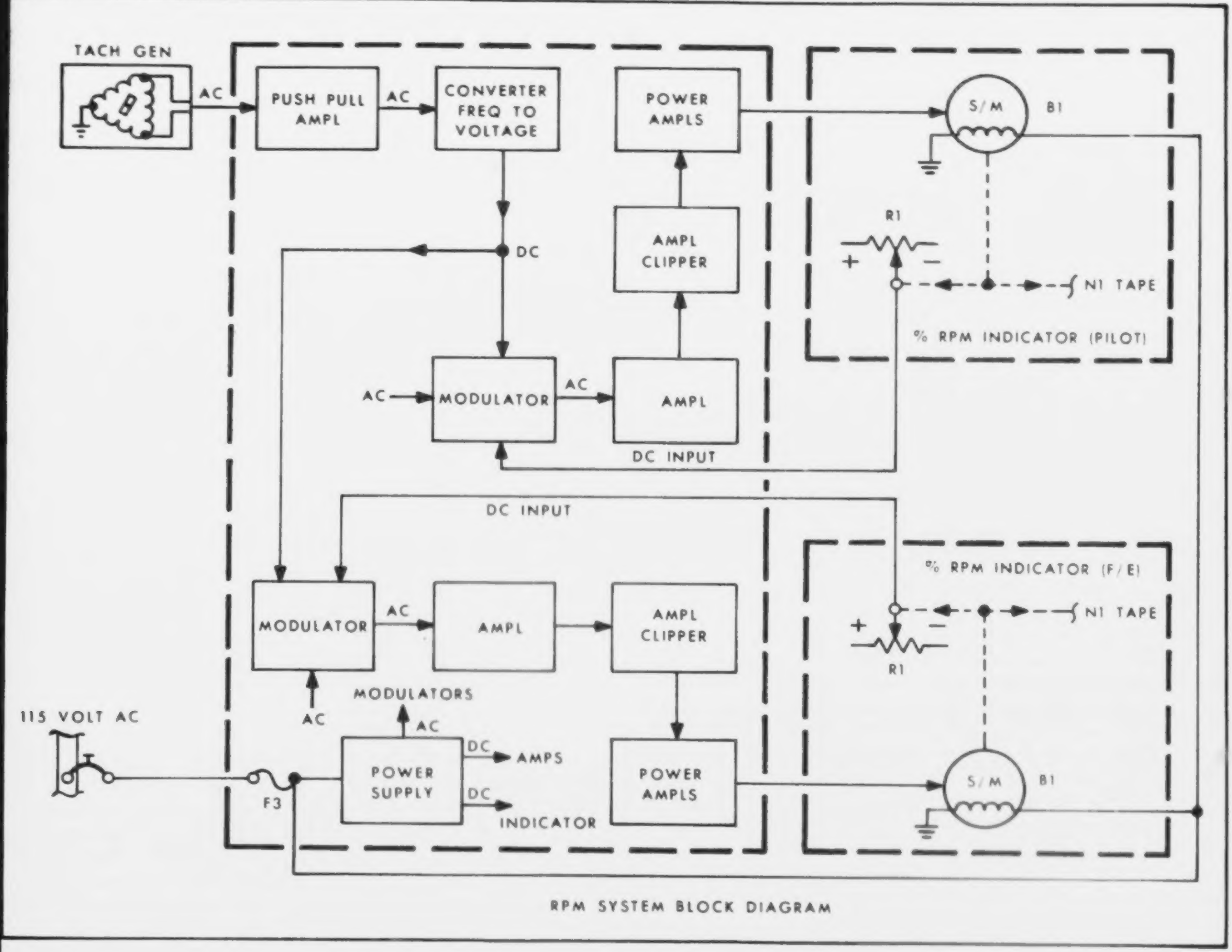

TACH GEN
AC
PUSH PULL AMPL
AC
CONVERTER FREQ TO VOLTAGE
POWER AMPLS
S/M
B1
AMPL CLIPPER
R1
+
−
DC
N1 TAPE
% RPM INDICATOR (PILOT)
AC
AC
MODULATOR
AMPL
DC INPUT
DC INPUT
% RPM INDICATOR (F/E)
MODULATOR
AC
AMPL
AMPL CLIPPER
N1 TAPE
+
−
R1
AC
MODULATORS
AC
115 VOLT AC
DC
AMPS
POWER SUPPLY
DC
INDICATOR
F3
POWER AMPLS
S/M
B1
RPM SYSTEM BLOCK DIAGRAM

Figure 6–2. Vertical-scale tachometer system block diagram.

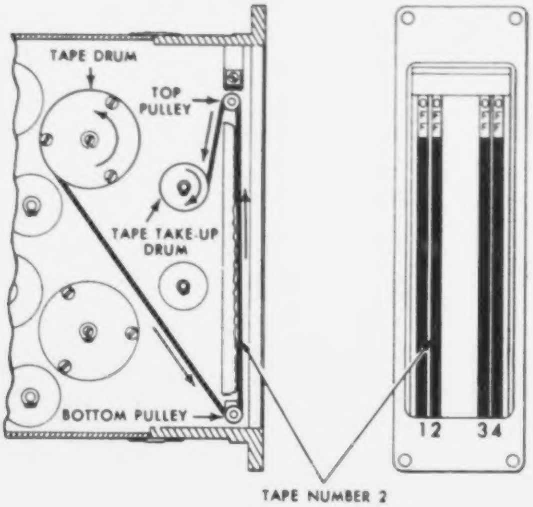


Figure 6-3. Tape threading arrangement.

cause the servomotor to drive upscale. The phasing of the signal is referenced to line voltage.

From the modulator, the signal takes the same path to the servomotor as explained previously. As the servomotor drives, the tape is positioned to show the rpm increase. At the same time, the wiper of R1 is moved. The motor continues to drive until the DC voltage felt on the wiper of R1 is of sufficient strength to cancel the converter DC signal to the modulator.

The magnitudes of the DC signal inputs to the modulator determine the direction the servomotor drives. To cause the motor to drive upscale, the DC signal from the converter is greater than the DC signal from R1. To cause the motor to drive downscale, the DC signal from R1 is greater than the DC signal from the converter. When this condition arises, the AC signals produced by the modulator are 180° out of phase with each other. For example, when the generator frequency increases, the DC output from the converter increases. In this case, the DC output voltage from the converter is now greater than the DC feedback voltage from R1. The modulator now produces an AC signal that is in phase with line voltage. The servomotor drives to position the tape upscale. If the generator frequency decreases, the DC output from the converter is less than the DC feedback from R1. Now the modulator produces an AC signal that is 180° out of phase with line voltage. The servomotor drives downscale. This completes our discussion of the rpm indicating system. Now take a look at the EGT indicating systems.

Exercises (667):

1. Match components of the vertical scale rpm indicating system listed in column A with their functions/description listed in column B. Write the correct letter in the space provided. Some functions/descriptions are used more than once.

Column A

Components

____ (1) Converter power supply.
____ (2) Converter DC output.
____ (3) Modulator circuits.
____ (4) Amplifier clipper.
____ (5) Indicator gear train.
____ (6) Indicator tape.
____ (7) Spiral spring.
____ (8) Tachometer generator.

Column B

Functions/ Description

a. Removes the word "OFF" from view.
b. Positions the indicator tape.
c. Supplies an AC output as a reference for the modulator circuits.
d. Operates on a 115-VAC input.
e. Supplies a small AC output that is amplified and sent to the control phase of the servomotor in the indicator.
f. Determine the direction the servomotor drives.
g. Moves tape downscale when power is removed.
h. Positions the wiper of R1.
i. Supplies a regulated DC output to the indicator amplifiers.
j. Changes a small DC input to a small AC output.
k. Indicates rpm in percent.
l. Supplies a DC output as a reference for potentiometer R1 in the indicators.
m. Supplies a 3-phase AC voltage to the push-pull amplifier.
n. Magnitude depends on the input frequency.

668. Identify the function or description of given components of the vertical scale EGT.

EGT System Operation. To begin our discussion of the EGT indicating system, again we must establish a starting point. You should recall, from our discussion of the vertical scale indicators, that when no power is applied to the system, the word "OFF" appears at the top of the indicator. Because no power is applied to the system, the spiral spring in the tape drum has rotated the gear train backwards and caused the word "OFF" to appear. At the same time, the wiper of R1 in the indicator has been moved to a position lower than normal. So, with these thoughts in mind, let's apply power to the system. Remember, now, that the engines are not running.

Notice in figure 6-4 that the AC voltage is applied through fuse F2 in the converter unit. From fuse F2, the AC voltage is applied to the power supply of the EGT channel. The power supply furnishes the DC voltages to the amplifiers and the DC reference voltage to R1 in the pilot's and flight engineer's indicators. The AC voltage is also supplied to the indicators for servomotor excitation.

Notice also in figure 6-4 that the thermocouple circuit is connected to the cold junction compensator of the EGT channel. The cold junction compensator provides a constant DC millivolt reference voltage regardless of temperature changes. Now, when power is applied to the system, the DC millivolt signal produced by the cold junction compensator is higher in magnitude than the DC feedback signal from R1 in the indicator. This DC millivolt signal is supplied to the dual chopper shown in figure 6-4. The dual chopper contains two independent choppers, one for the pilot's and one for the flight engineer's indicating

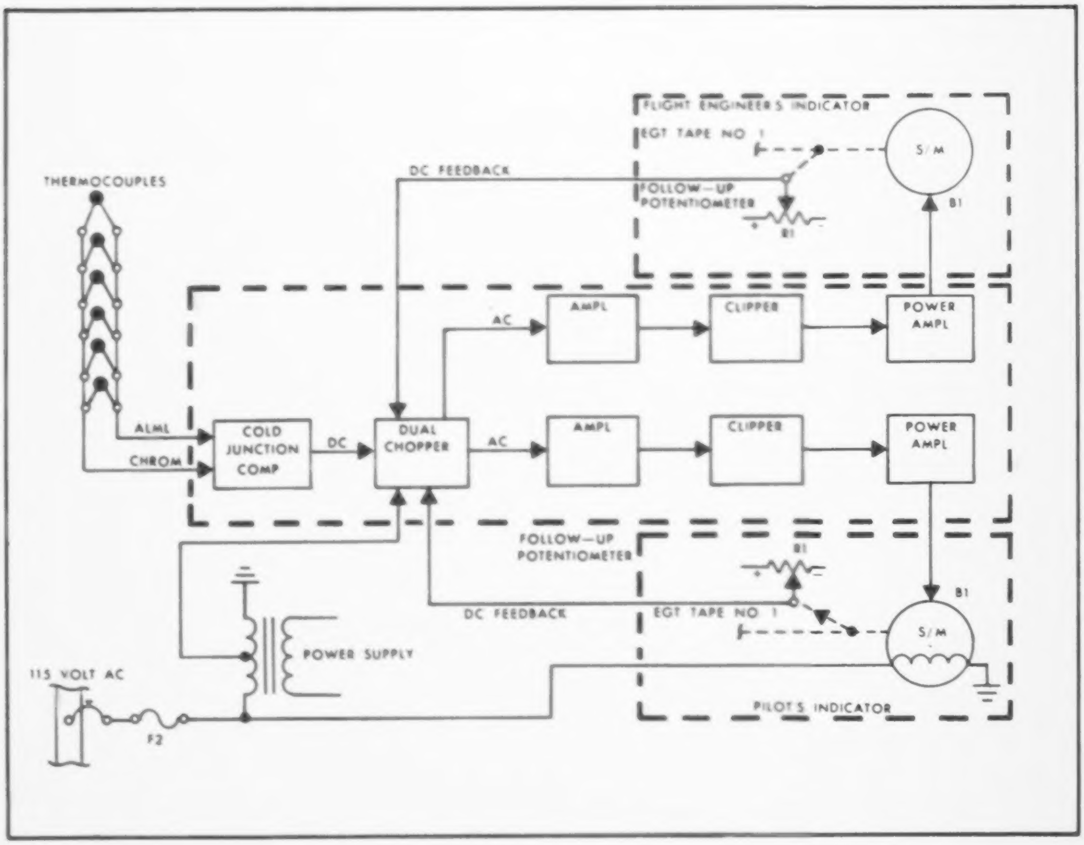

FLIGHT ENGINEER'S INDICATOR
EGT TAPE NO. 1
S/M
DC FEEDBACK
THERMOCOUPLES
FOLLOW—UP POTENTIOMETER
R1
B1
AC
AMPL
CLIPPER
POWER AMPL
ALML
CHROM
COLD JUNCTION COMP
DC
DUAL CHOPPER
AC
AMPL
CLIPPER
POWER AMPL
FOLLOW—UP POTENTIOMETER
R1
B1
DC FEEDBACK
EGT TAPE NO. 1
S/M
POWER SUPPLY
115 VOLT AC
F2
PILOT'S INDICATOR

Figure 6-4. Vertical-scale EGT system block diagram.

system. From this point on, both circuits are the same. For this reason, we will discuss only the pilot's system.

In the chopper circuit, the DC millivolt signal from the cold junction compensator is changed to a 400-Hz AC signal. The AC signal is supplied to an amplifier, where it is boosted in strength. The boosted signal is fed to a clipper circuit. Here the alternation of the signal that is not needed is clipped. The clipped signal is then amplified by the power amplifier. The output of the power amplifier is fed to the control phase of the servomotor. As the motor drives, the tape and the wiper of R1 are repositioned. The servomotor continues to drive until the DC voltage felt on the wiper of R1 is of the same value as the chopper. At this time, the servomotor stops and the word "OFF" is removed from view. The indicator now appears blank except for the calibrated scale.

Now let's start the engine and see what happens. When the engine is started and heat is applied to the thermocouples, a DC millivolt signal is produced in the thermocouple circuit. The DC millivolt signal is applied to the cold junction compensator. This increase in voltage is applied to the dual chopper. The DC signal is again higher than the feedback signal from R1. So again the chopper produces a 400-Hz AC signal. The signal from the chopper takes the same path to the servomotor as previously described. The motor drives to position the tape upscale and shows the increase in EGT. The wiper of R1 is moved to cancel the input signal to the chopper.

The phasing of the signal that causes the motor to drive upscale or downscale is decided at the chopper. When the DC signal voltage produced by the thermocouple circuit is greater than the feedback voltage from R1, the motor drives to position the tape upscale. When the DC feedback voltage is greater than the DC signal from the thermocouples (decrease in EGT), the motor drives to position the tape downscale. The tape is mechanically positioned in the same manner as described for the rpm indicating system.

Exercises (668) **:**

1. Match components of the vertical scale EGT listed in column A with their functions/descriptions listed in column B. Write the correct letter in the space provided. Some functions/descriptions are used more than once.

Column A *Components*	*Column B* *Functions/ Descriptions*
____ (1) 115 VAC.	
____ (2) Cold junction compensator.	a. Produces a DC feedback signal.
	b. Positions the wiper of R1.

Column A

Components

- ____ (3) Dual chopper.
- ____ (4) Clipper.
- ____ (5) Servomotor.
- ____ (6) Resistor R1.

Column B

Functions/ Descriptions

c. Produces a DC millivolt signal higher than the R1 signal when power is first applied.
d. Applied to the primary of EGT power supply transformer.
e. Sends a signal to the power amplifier for amplification for use by the control phase of the servomotor.
f. Sensitive to temperature changes.
g. Repositions the indicator tape.
h. Decides phasing of R1 and cold junction signals.
i. Supplies excitation to the indicator servomotors.
j. Produces a DC millivolt signal.
k. Changes input DC millivolt signal to a 400-Hz AC output.
l. Cancels input signals to the chopper.
m. Provides a constant DC millivolt reference voltage.

669. Identify the function or application of given components and signals of the vertical scale fuel flow indicating system.

Fuel Flow System Operation. The fuel flow indicating system is a servo-driven, synchro-controlled system. The indicator consists of four independent tape indicators. Again, all four indicating systems operate the same, so we will discuss only one system.

To establish a beginning point, let's set up the same conditions established for the other tape systems that we have discussed thus far. We will begin with no power applied to the system and the engines not running.

Figure 6-5 shows a block diagram of one fuel flow indicating system. Notice in figure 6-5 that the 115-volt AC power passes through the fuse to a junction. From the junction, the 115-volt AC is applied up to the amplifier power supply. Notice that it is also applied to the fuel flow XMTR motor. Follow the same wire from the junction to the right; you will find that the 115-volt AC power is also applied to the fuel flow XMTR transmitting synchro (TX). From the junction just above the fuel flow XMTR TX, the AC power is applied to the servomotors of the pilot's and flight engineer's indicators.

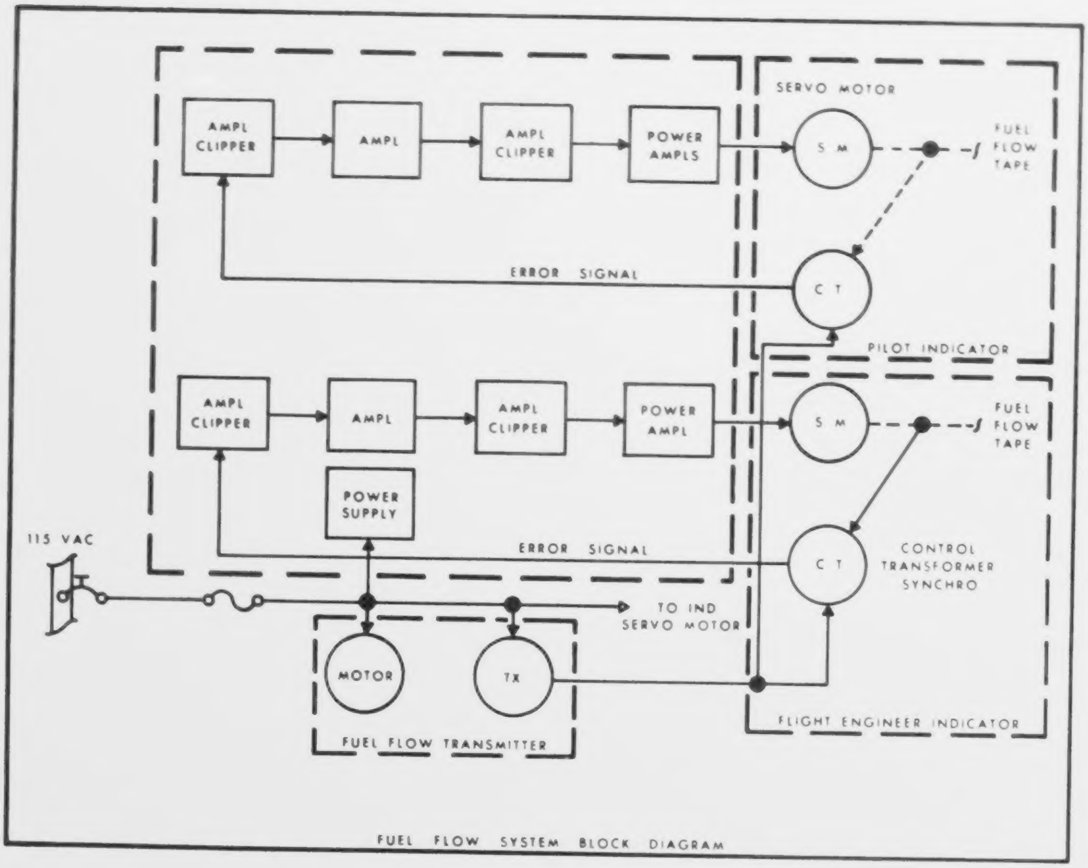

AMPL CLIPPER
AMPL
AMPL CLIPPER
POWER AMPLS
SERVO MOTOR
S M
FUEL FLOW TAPE
ERROR SIGNAL
C T
PILOT INDICATOR
AMPL CLIPPER
AMPL
AMPL CLIPPER
POWER AMPL
S M
FUEL FLOW TAPE
POWER SUPPLY
115 VAC
ERROR SIGNAL
C T
CONTROL TRANSFORMER SYNCHRO
TO IND SERVO MOTOR
MOTOR
TX
FUEL FLOW TRANSMITTER
FLIGHT ENGINEER INDICATOR
FUEL FLOW SYSTEM BLOCK DIAGRAM

Figure 6–5. Vertical-scale fuel flow system block diagram.

The power supply furnishes the regulated DC voltages necessary for amplifier operation. The 115-volt AC power is supplied to the fuel flow XMTR motor to drive the impeller at the constant 60 rpm. The 115-volt AC power is applied to the XMTR TX for rotor excitation and to the indicator servomotors for fixed-phase reference voltage.

When power is applied to the system, a signal is induced into the stators of the XMTR TX. This signal is transferred electrically to the stators of the control transformers (CT) in the pilot's and the flight engineer's indicators. From this point, the pilot's and the flight engineer's circuits are independent, but the circuit operation is identical. So we will discuss only the pilot's indicating system. When the signal from the stators of the XMTR TX is felt in the stators of the pilot's indicator CT, a small error signal is induced into the rotor of the CT. The error signal from the rotor is applied to the circuits of the amplifier clipper. The alternation of the signal that is not needed is clipped. The clipped signal is then amplified and sent to another amplifier clipper. Again the signal is clipped and supplied to the power amplifier. The output from the power amplifier is fed to the control phase of the indicator servomotor (SM).

When the control phase of the SM is energized, the motor starts to drive. As the motor drives, the gear train in the indicator positions the tape and, at the same time, turns the rotor of the CT toward the NULL position. The motor continues to drive until the rotor of the CT is moved perpendicular to the resultant magnetic field. At this time, the rotor is nulled, no error signal exists, and the motor stops. The tape is driven just far enough to remove the word "OFF" from view. The indicator now appears blank except for the calibrated scale. Notice what happens when the engines are started.

As an engine is started, fuel starts to flow through the XMTR. When fuel flows through the XMTR, the rotor of the XMTR TX is moved proportionally as the rate of flow increases through the XMTR. Since the rotor of the XMTR TX has moved, the stators of the TX now have different voltages induced. Because the stators of the indicator CT are directly connected to the stators of the TX, this change in stator voltage is felt at the CT. Now the rotor of the CT is no longer nulled, and an error signal is induced in the rotor. The error signal from the rotor takes the same path to the SM as previously described. The SM drives to position the tape upscale and, at the same time, positions the rotor of the CT to null.

If fuel flow through the XMTR decreases, a signal opposite the phasing that caused the SM to drive upscale is induced into the rotor of the indicator CT. Consequently, the SM drives in the opposite direction and allows the spring to position the tape downscale.

Exercises (669):

1. When is the rotor of the control transformer considered at NULL?

2. It is decided how the signal will be phased to drive the fuel flow indicator servomotor up or downscale in the ________ ________ ________.

3. Match components and signals of the vertical scale fuel flow indicating system listed in column A to their functions/applications listed in column B. Write the correct number in the space provided. Some functions/applications are used more than once and some are not used.

Column A

Components/ Signals

_____ (1) 115-VAC input.
_____ (2) Amplifier power supply.
_____ (3) Transmitter TX.
_____ (4) Power amplifier.

Column B

Functions/ Applications

a. Drives transmitter impeller at a constant 60 rpm.
b. Sends a signal to the control phase of the indicator servomotor.
c. Applied to the amplifier power supply.
d. Supplies a negative feedback signal to the power amplifiers.
e. Supplies a regulated DC to the amplifiers.
f. Applied to the fuel flow transmitter TX rotor.
g. Sends a signal to the indicator CT stators.
h. Drives the transmitter impeller at a constant 400 rpm.
i. Applied to the indicator servomotor fixed phase.

670. Identify the functions of given components of the vertical scale EPR indicating system.

EPR System Operation. The EPR indicating system for each engine consists of two independent servoloops. One servoloop, located in the transducer, senses the pressure ratio and positions the rotor of a synchro unit. The other servoloop is located in the indicator. It receives the synchro signal from the EPR transducer and positions the indicating tape to show the EPR.

Figure 6-6 shows a block diagram of the EPR indicating system for one engine. The systems for the other engines operate identically. Notice in figure 6-6 that the 115-volt AC is applied to the power supply of the transducer. The power supply furnishes regulated DC operating voltages to the transducer signal amplifier. The power supply also furnishes an excitation voltage to the transducer SM, the synchro rotor, and the signal-sensing circuit. The 115-volt AC power is also supplied to the servoloops of the pilot's and the flight engineer's indicators (not shown in the fig.).

The indicators are arranged so that when no power is applied to the system, the spiral spring moves the gear train backward. This causes the word "OFF" to appear at the top of the indicator. At the same time, the rotor for the indicator synchro is turned a little past null. At this point we begin our discussion.

When power is applied to the system, a voltage is induced into the stators of the synchro in the transducer. In

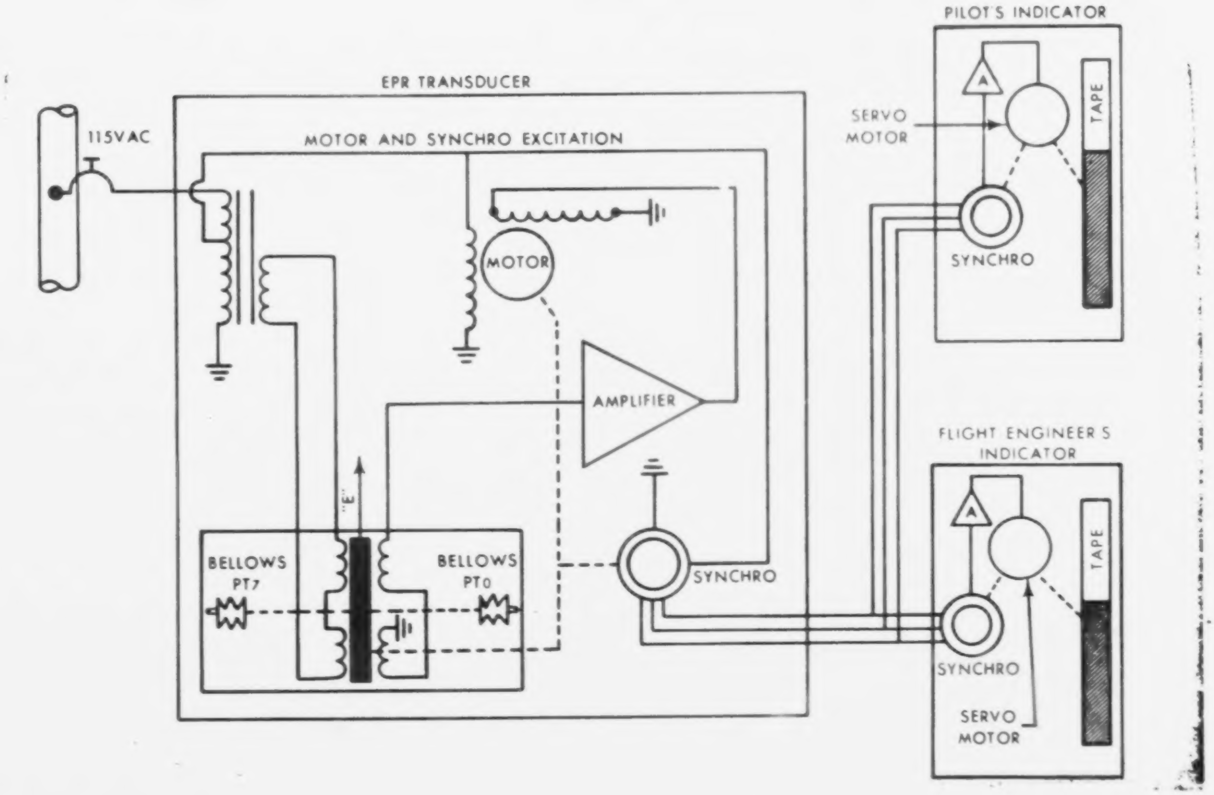


Figure 6-6. Vertical-scale EPR system block diagram.

figure 6-6, the stators of the synchro in the transducer are directly connected to the stators of the synchros in the pilot's and the flight engineer's EPR indicators. From this point, the EPR systems operate identically.

The voltage that is induced into the transducer synchro stators is transferred to the stators of the synchro in the indicator. Because the rotor of the indicator synchro is not at NULL, an error signal is induced. The error signal from the rotor is fed to the indicator amplifier. The signal is amplified, discriminated, and supplied to the control phase winding of the SM. When the control phase is energized, the motor starts to drive. As the SM drives, the gear train positions the tape and the rotor of the synchro toward NULL. The motor continues to drive until the rotor of the indicator synchro is perpendicular to the stator's magnetic field. At this time the motor stops.

The tape has moved just far enough to remove the word "OFF" from view, and the indicator appears blank except for the calibrated scale. Now the engines start.

As an engine is started, a pressure ratio between the engine inlet pressure and the engine exhaust pressure is sensed by the dual bellows (Pt_2 and Pt_2) in the transducer. The movement of the dual bellows causes the variable reluctance core of the signal-sensing unit to move up. This movement, in turn, causes the inductive bridge to become unbalanced. The result is an error signal applied to the transducer amplifier. The signal is amplified, discriminated, and supplied to the control phase of the transducer SM. As the SM drives, a gear train positions the rotor of the transducer synchro. At the same time, it moves the variable reluctance core of the signal sensor. The motor continues to drive until the variable reluctance core is moved down enough to rebalance the inductive bridge circuit of the signal sensor.

Now the rotor of the indicator synchro is no longer null. The movement of the rotor in the transducer synchro changed the induced voltage in the stators. Since the stators of the synchros are directly connected, this voltage change is also felt in the stators of the indicator synchro. Because of the voltage change in the stators, an error signal is induced into the rotor of the indicator synchro. The signal induced into the rotor is supplied to the indicator amplifier. The signal is amplified and discriminated by the amplifier. The output from the amplifier is supplied to the control phase of the SM. As the motor drives, the tape is positioned upscale to show the increase in EPR, and the rotor of the synchro is turned toward NULL. The motor continues to drive until the rotor of the indicator synchro is at NULL. At this time the motor stops.

If the EPR of the engine decreases, the same sequence of events takes place. However, the phasing of all the signals is opposite those for an increase in EPR. Consequently, the motors drive in the opposite direction, and the spring winds the tape downscale. This completes our discussion of the vertical scale engine instrument system operation.

Exercises (670):

1. Match components of the vertical scale EPR indicating system listed in column A with their functions listed in column B. Write the correct letter in the space provided. Some functions are used more than once and some are not used.

Column A	*Column B*
____(1) Transducer power supply.	a. Supplies a signal to the indicator SM variable phase winding.
____(2) Transducer synchro.	b. Furnishes a regulated DC operating voltage to the signal amplifier.
____(3) Indicator amplifier.	c. Senses the difference between engine inlet and exhaust.
____(4) Transducer dual bellows.	d. Supplies an error signal to the indicator amplifier.
____(5) Transducer inductive bridge circuit.	e. Transfers signal to the indicator synchro.
	f. Senses the sum of engine inlet and exhaust pressures.
	g. Supplies an error signal to the transducer amplifier.
	h. Furnishes excitation voltage to the transducer SM.
	i. Moves the core of the variable reluctance signal sensing unit.
	j. Supplies a signal to the indicator SM control phase winding.

671. State vertical-scale engine instrument inspection and operational check procedures.

Inspection and Operational Check. Inspection requirements for the vertical-scale engine instrument systems consist of essentially the same check as for the dial-type indicating systems. Check the indicators for security of mounting, cover-glass condition, internal lighting operation, and condition and proper placement of range markings. Check the converter unit for security of mounting, shock mount condition, and general overall condition. Check the engine-mounted signal-sensing components for security of mounting, proper safetying, and general overall condition. While performing the inspection of the components, you also check the electrical wiring and connectors for defects.

Your first step in performing an operational check of the vertical-scale engine instrument system is to make sure that power is applied to the system. Once power is applied, check to make sure that the word "OFF" moves from view. To further operationally check the system, start the engines and check to see that the tapes move smoothly to the proper indications. If, for some maintenance reasons, the engines cannot be operated, the vertical-scale engine instrument system analyzer test set can be used to simulate enginerun conditions.

Exercises (671):

1. When inspecting a vertical scale engine instrument system, what items should you check on the vertical-scale indicators?

2. During an operational check of the vertical-scale engine instrument system, what do you check the indicators for, immediately after applying power to the system?

Test Equipment. There are two pieces of test equipment available for testing the vertical-scale engine instrument system and its components. They are the vertical-scale engine instrument system (EIS) analyzer and the converter output test set. So that you will better understand the use of each tester, we discuss each one separately.

672. Identify the function of given components of the EIS analyzer.

EIS analyzer. The EIS analyzer is a portable test set. It is used to test the vertical-scale engine instrument system on the aircraft. The analyzer simulates the engine inputs to the converter, thereby testing the converter and indicators as a system. The analyzer also simulates converter output to the indicators for testing each indicator tape individually. The above tests are performed on the aircraft. The necessary cables for connecting the analyzer to the converter and the indicators are supplied with the tester. Instructions for connecting the cables for the various tests are listed in the operation and service instructions technical order for the analyzer.

Figure 6-7 shows the control panel of the EIS analyzer. Refer to figure 6-7 as we discuss each of the switches and connectors. All items on the control panel are identified by function and number.

The analyzer requires a power source of 115-volt, 400-Hz, single-phase AC. You connect the AC power to the analyzer through connector J104 (54). The remaining connectors used to connect the analyzer to the system. The connectors depend upon the test being performed.

The turbine station switch (13) has two positions, N1 and N2. You use this switch to select the analyzer rpm output to the N1 or N2 rpm indicating system. You also use the switch to select the analyzer rpm output to the N1 and N2 rpm indicator when performing the indicator test on the aircraft. Use the exhaust gas temperature switch (14) to select the various test points when testing the EGT indicating system. The switch provides the same function when testing the EGT indicator. Use the percent rpm switch (15) to select the various test points when performing test of the rpm systems or indicators. Use engine selector switch (36) to select the engine for which the tests are being performed. Use the fuel flow switch (38) to select fuel flow system test points. Also use this switch for the same purpose when performing tests on the fuel flow indicator.

Test selector switch (37) allows you to select either the entire system or the individual indicator being tested. The exact function of the other switches depends upon the position of this switch. For example, if you desire to test the entire system on the aircraft, place this switch to SYSTEM. With the engine selector switch (36) placed on 1, you can check the following systems of No. 1 engine: the N1 and N2 rpm systems, the EGT system, and the fuel flow system.

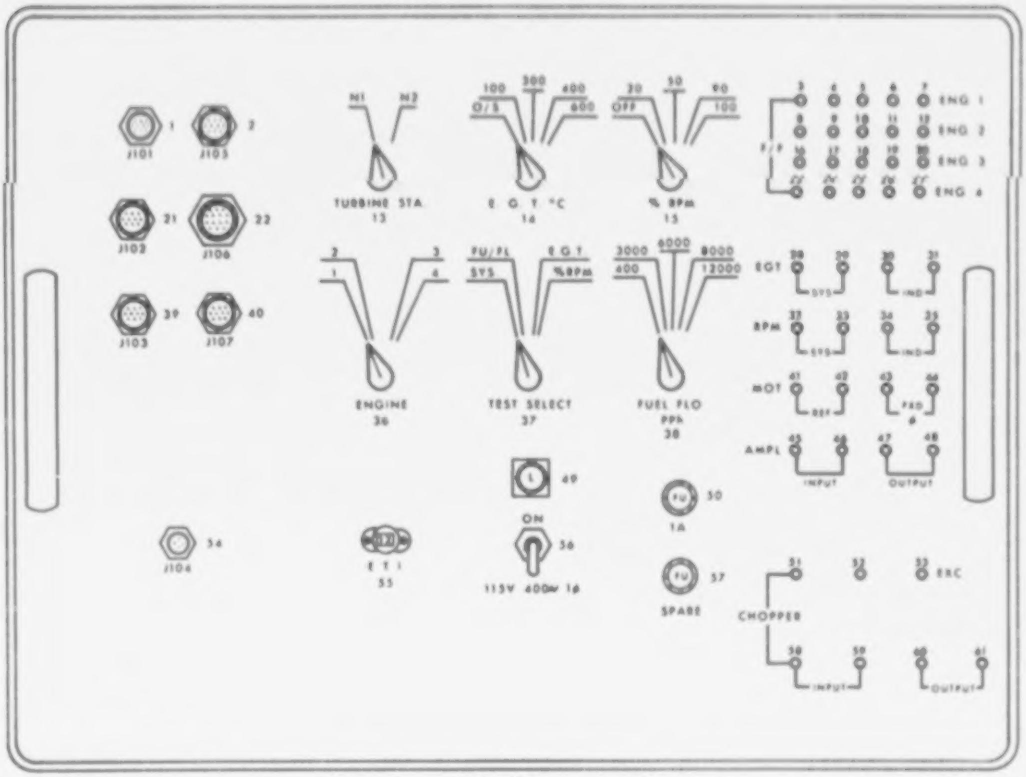

1
J101
2
J105
21
J102
22
J106
39
J103
40
J107
N1
N2
TURBINE STA
13
100
300
400
O/S
600
E G T °C
14
30
50
90
OFF
100
% RPM
15
ENG 1
ENG 2
ENG 3
ENG 4
2
3
1
4
ENGINE
36
FU/FL
E G T
SYS
%RPM
TEST SELECT
37
3000
6000
8000
400
12000
FUEL FLO
PPh
38
EGT
SYS
IND
RPM
MOT
REF
PAD
AMPL
INPUT
OUTPUT
49
ON
56
115V 400~ 1φ
50
1A
57
SPARE
54
J104
E T I
55
CHOPPER
EXC

Figure 6–7. EIS analyzer.

These three checks are made simultaneously. If you desire to check the EGT indicator individually, place the test select switch (37) to EGT. Use the engine selector switch (36) to select each tape of the indicator. Use the EGT switch (14) selects the various test points.

Power to the tester is controlled by the 115-volt, 400-Hz, single-phase switch (56). When this switch is turned to ON, the indicator lamp (49) is illuminated. The tester circuits are protected by a 1-ampere fuse (50), located on the front panel. A spare fuse (57) is also provided. The ETI indicator (55) is an elapsed time indicator. This indicator keeps track of how many hours the analyzer has been used. The various test jacks, on the right side of the analyzer, are used to calibrate and troubleshoot the analyzer.

In addition to the previously described analyzer, some of the testers we have discussed in the previous chapters may be used to test the vertical scale engine instrument systems. For example, the synchro tester described in the chapter on synchronous indicating systems may be used to check the EPR indicating systems. However, an adapter cable must be locally fabricated to connect the tester to the aircraft wiring connector from the transducer. Instructions for fabricating the adapter cable can be found in the applicable aircraft TO. The TTU 27/E tachometer tester can be used to check the rpm indicating system. The tester is connected to the tachometer generator wiring connector. It simulates the generator output to the system. A Jetcal tester is used to apply heat to the EGT thermocouple probes, thereby simulating actual EGT temperatures.

Exercises (672):

1. Match components of the EIS analyzer listed in column A with their functions listed in column B. Write the correct letter in the space provided. Some functions are used more than once and some are not used.

Column A

Components

____ (1) Connector J104.
____ (2) Turbine station switch.
____ (3) Exhaust gas temperature switch.
____ (4) Percent rpm switch.
____ (5) Engine selector switch.
____ (6) Fuel flow switch.
____ (7) Test selector switch.
____ (8) Power switch.
____ (9) Indicator lamp.
____ (10) ETI indicator.
____ (11) Test jacks.

Column B

Functions

a. Selects various test points when checking EGT indicating systems.
b. Selects various test points when checking rpm indicators.
c. Controls electrical power to the test set.
d. Selects various test points when checking fuel flow systems.
e. Used to calibrate and troubleshoot the test set.
f. Connects 115-volts, 400-Hz, single-phase, AC to the tester.
g. Selects analyzer rpm outputs to the N1 or N2 rpm indicating system.
h. Selects various test points when checking rpm systems.

Column A

Components

Column B

Functions

i. Selects the engine system on which you are performing a check.
j. Illuminates when power is applied to the test set.
k. Selects various test points when checking fuel flow indicators.
l. Indicates the amount of hours since the tester was overhauled.
m. Selects various test points when checking EGT indicators.
n. Provides a safety device in the event of an overload.
o. Indicates the amount of hours the tester has been used.
p. Selects either the entire system or an individual indicator.
q. Connects 115-volts, 400-Hz, three-phase AC to the tester.
r. Illuminates to indicate a satisfactory test reading.

673. Identify the functions of given components of the converter test set.

Converter test set. The converter test set is used in conjunction with the EIS analyzer (previously described). It is used to perform bench checks on the converter unit. The required power signal inputs to the converter unit are controlled by the EIS analyzer. The converter test set then monitors the converter outputs, which are the responses to the EIS analyzer inputs. The cables for connecting the test set to the converter are supplied with the tester. A special bench power cable is also supplied with the tester.

The converter test set, shown in figure 6-8, requires 115-volt, 400-Hz, single-phase power for operation. The AC power is connected to the test set through connector J-5 (31). The remaining connectors on the left side of the panel are used to connect the test set to the converter. Instructions for connecting the cables for the various tests are listed in the applicable tester TO.

Refer to figure 6-8 as we discuss the purpose of each of the switches and indicators on the converter test set control panel. We will identify each item by its function and corresponding number on the control panel.

The VTVM (3) is needed for measuring the indicator SM fixed-phase excitation voltage output from the converter. The VTVM is also used to measure the indicator SM control phase voltage when the servoloops are at NULL. Followup potentiometer N1 (4) simulates the followup potentiometers in the N1 rpm indicators. Followup potentiometer N2 (8) does the same as N1 (4). Followup potentiometer EGT (26) simulates the followup potentiometers in the EGT indicators. These potentiometers provide a DC feedback voltage necessary to complete the N1, N2, and EGT servoloops in the converter. Followup potentiometer selector switch (36) selects the engine servoloop of the converter to which the followup potentiometers are connected.

CT (12) simulates the CTs of the fuel flow indicators. Fuel flow TX selector switch (22) selects the engine fuel flow servoloop of the converter to which the CT (12) is connected. The CT completes the fuel flow servoloop in the converter.

The DC microammeter (13) is provided for monitoring the N1, N2, and EGT indicator followup potentiometer excitation voltage outputs from the converter. Followup *potentiometer excitation select switch (23) selects the* followup potentiometer excitation to be read on the microammeter (13).

Test select switch (30) selects the indicator SM control phase and fixed-phase voltage to be monitored on VTVM (3). The yellow-black and blue-black fuel flow positions of this switch provide a means of monitoring the voltages applied to the stators of the control transformer (12). The control phase selector switch (37) and the motor excitation switch (38) are used in conjunction with the test selector switch (30). These switches select the engine servoloop control and fixed-phase voltages to be monitored by VTVM (3).

The 115-volt AC power to the tester circuits is controlled by the power switch (34). When the switch is placed in the ON position, the POWER ON lamp (32) illuminates. The tester circuits are protected by a 1/4-ampere fuse (35) located on the front panel. A spare fuse (33) is also provided on the front panel. systems. We will discuss troubleshooting of the indicating

Exercises (673):

1. Match components of the converter test set listed in column A with their functions listed in column **B**. Write the correct letter in the space provided. Some functions are used more than once and some are not used.

Column A

Components

_____ (1) Connector J5.
_____ (2) Connectors J1 thru J4.
_____ (3) VTVM.
_____ (4) Followup potentiometer N1.
_____ (5) Followup potentiometer N2.
_____ (6) Followup potentiometer EGT.
_____ (7) Followup potentiometer selector switch.
_____ (8) CT.
_____ (9) Fuel flow TX selector switch.
_____18u'(10) microammeter.
_____ (11) Followup potentiometer excitation select switch.
_____ (12) Test select switch.
_____ (13) Control phase selector switch and motor excitation switch.

Column B

Functions

a. Provides a DC feedback voltage to complete the N1, N2, or EGT servoloop in the converter.
b. Selects the engine servoloop of the converter to which the CT is connected.
c. Measures indicator SM control phase voltage when the servoloops are at NULL.
d. Provides a means for connecting 115-volt, 400-Hz, single-phase power for test set operation.
e. Used in conjunction with test select switch to select the engine servoloop control and fixed-phase voltages to be monitored by the VTVM.
f. Selects the excitation to be read on the microammeter.
g. Completes the fuel flow servolop in the converter.
h. Provides a means for connecting 115-volt, 400-Hz, three-phase power for test set operation.
i. Measures input power to the converter test set.
j. Simulates the followup potentiometer in the N1 rpm indicators.

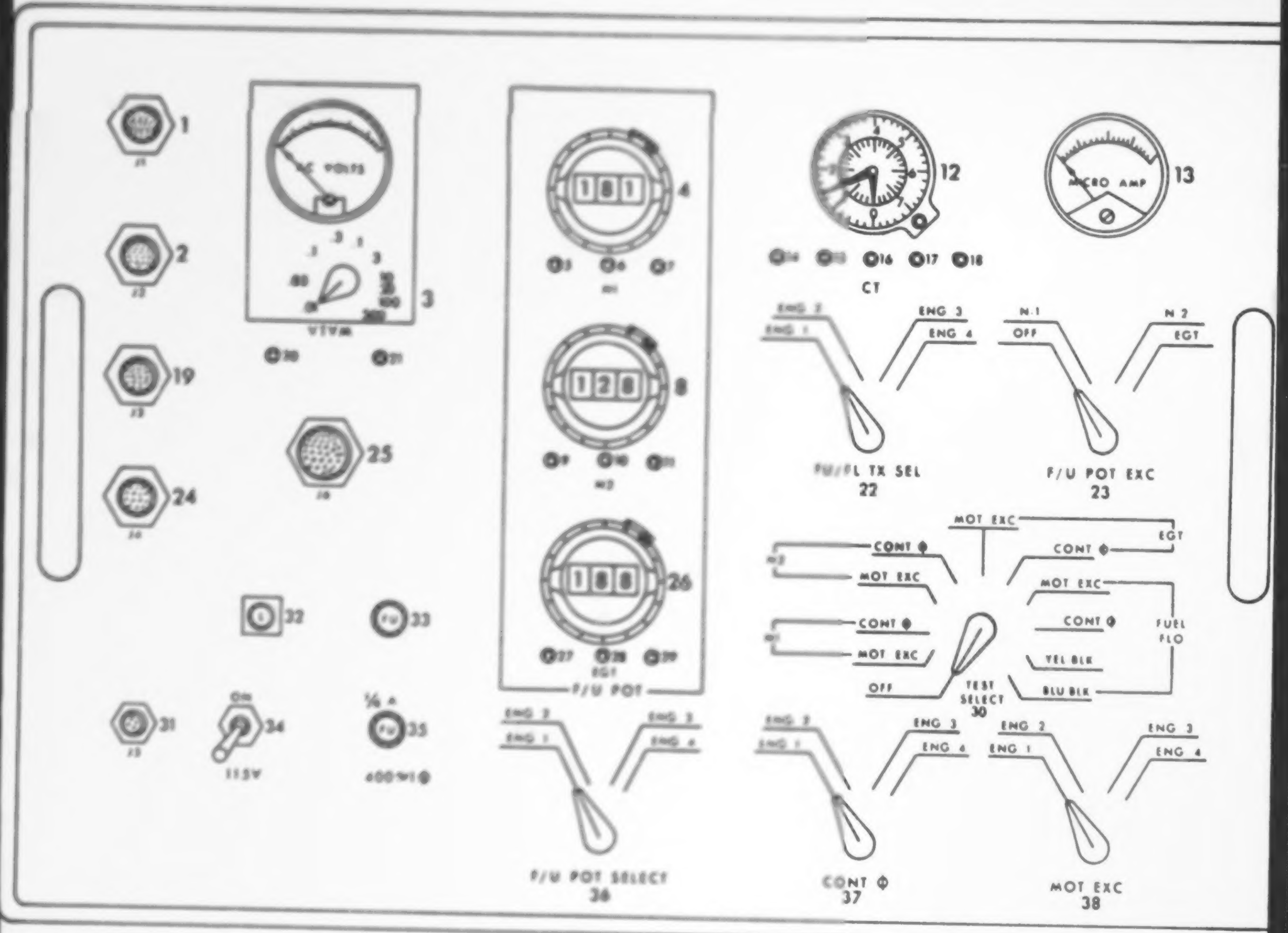

1
2
19
24
25
31
32
33
34
35
3
DC VOLTS
VTVM
ON
115V
4
8
26
EGT
F/U POT
12
13
MICRO AMP
CT
16
17
18
ENG 2
ENG 1
ENG 3
ENG 4
FU/FL TX SEL
22
N 1
OFF
N 2
EGT
F/U POT EXC
23
MOT EXC
CONT Φ
EGT
FUEL FLO
YEL BLK
BLU BLK
OFF
TEST SELECT
30
F/U POT SELECT
36
CONT Φ
37
MOT EXC
38

Figure 6-8. Converter test set.

Column A *Components*	*Column B* *Functions*
k. Selects the engine to which the converter servoloop is connected.	
l. Monitors N1, N2, and EGT indicator followup potentiometer excitation voltage outputs from the converter.	
m. Provides a means of monitoring the voltages applied to the stators of the CT.	
n. Provides a means for connecting the test set to the converter.	
o. Measures indicator SM fixed-phase excitation voltage from the converter.	
p. Simulates the followup potentiometers in the N2 rpm indicators.	
q. Selects the indicator SM control phase and fixed-phase voltage to be monitored on the VTVM.	
r. Simulates fuel flow indicator CTs.	
s. Provides a means for connecting the test set to the EIS analyzer.	
t. Simulates the followup potentiometers in the EGT indicators.	

674. Identify common vertical scale engine instrument system troubles, name test equipment, and, with a diagram and hypothetical trouble, state the probable indication.

Troubleshooting. To adequately discuss troubleshooting of the vertical scale instruments, we must discuss each system separately. So let's begin with the troubleshooting of the rpm system.

RPM system troubleshooting. The most common troubles that occur in the RPM system are fluctuations and no rpm indications. So take a look at each trouble separately. We will begin with a fluctuating indication.

Look back at figure 6-2, and you will see that we have a two-indicator system. Since the fluctuation normally appears on both indicators, you must determine a common point for both indicators. Notice in figure 6-2 that the common point for both indicators is the junction point between the converter and the modulators. So the output of the tachometer generator is common to both indicators from the junction point. As with the dial-type rpm systems, a fluctuation is normally caused by intermittent open wiring or a defective generator. The wiring from the generator to the converter unit is checked by the use of a multimeter. If the wiring checks good, the generator is probably defective.

You can check the entire system, with the exception of the generator, by connecting a TTU 27/E tachometer tester to the generator connector. This check can insure that the channel board in the converter is good. Then you have isolated the trouble to a defective generator.

The most common cause of no rpm indications is a sheared generator drive shaft. You can use the same process of elimination to isolate the trouble as you did for a fluctuation. You must also remember that all of the vertical scale engine indicating systems are closed servoloops. They are subject to the same troubles that appear in any servoloop. For example, if the converter output DC is lost to the modulator circuits, both indicators will drive off-scale low. The reason for this is that only the feedback signals will be present at the modulator. Without the DC signal from the converter, the modulators will only produce an AC signal of the proper phasing to drive the tape downscale. On the other hand, if the feedback signal is lost to one modulator, the indicator of that circuit will drive off-scale high. To isolate a defective channel board, you can interchange the suspected defective channel board with a known good channel board from another engine position.

Exercises (674):

1. Identify the two most common malfunctions in the vertical scale rpm indicating system.

2. Name the test set that can be used to check the entire rpm system at one time, except for the generator.

3. Referring to figure 6-2, state the indication the rpm indicators would show if the wire between the wiper of R1 in the pilot's indicator and the modulator opened. Why?

675. State the indications to expect on EGT indicators for given troubles.

EGT system troubleshooting. The most common troubles that occur in the EGT systems are high and low indications. Since a low EGT indication is the more common of the two, let's discuss this trouble first. A low indication normally appears on both indicators. So, again, you must locate a common point to both indicators. Look at figure 6-4 and you will see that the thermocouple circuit and the cold junction compensator are common to both indicators. The best and most accurate method of checking the thermocouple circuit is to apply known values to heat the thermocouples. you use the Jetcal tester to do this.

First apply the heat to each of the individual thermocouple probes. You do this to check the system for an increase in EGT as each of the probes is heated. If one probe fails to show an increase in EGT, that thermocouple is defective. If all of the probes show an increase in EGT, apply heat to all the probes simultaneously. If the indication is still low, the most probable cause is a defective converter unit channel board. The suspected defective channel board may be interchanged with a known good channel board from another engine position.

A high EGT indication is very rarely caused by a defective thermocouple circuit. The most probable cause of a high indication on both indicators is a defective channel board. Again, the channel boards may be interchanged to isolate the trouble. If the high indication appears on one indicator only, the indicator is the most probable cause.

Exercises (675):

1. Referring to figure 6-4, the indication on the EGT indicators if one or more thermocouples opened would be a ________ ________ .

2. The most probable cause of a high EGT indication on both EGT indicators on the vertical scale EGT system would be a _______ ________ ________ .

676. State the indication to expect on the fuel flow indicators for a given wiring problem.

Fuel flow system troubleshooting. Like the EGT system, the most common trouble with the fuel flow indicating system is a high or low indication. If you look at figure 6-5, you will see that the fuel flow system is also a two-indicator system. The common point for both indicators is the fuel flow transmitter signal output. So, if the high or low indication appears only on one indicator, the most probable cause is the indicator. However, if the trouble appears on both indicators, the most probable cause is the transmitter.

The vertical scale engine instrument system analyzer can be used to simulate the transmitter output signals. The step-by-step procedure for this check is found in the applicable tester TO. In this case, if the system checks good, you have isolated the trouble to a defective transmitter.

You are again reminded that the fuel flow indicating systems are synchro systems. The systems are subject to the same troubles that occur in any system of this type. These troubles and the procedures for isolating the troubles were covered in detail in a previous chapter on synchronous indicating systems.

Exercises (676):

1. Refer to figure 6-5. What indication would the fuel flow indicators show if the wire from the pilot's indicator CT to the amplifier clipper opened? Why?

677. State the indications to expect on the EPR indicators for given mafunctions.

EPR system troubleshooting. The most common troubles that occur in the EPR indicating systems are high and low EPR indications. The EPR signals from the transducer are connected directly to the EPR indicator. They do not go through the converter unit. The converter unit, therefore, cannot be a possible trouble source. Look back at figure 6-6 and notice that the signal from the transducer is applied directly to the pilot's and the flight engineer's indicators. If the trouble appeared in only one indicator, the possible causes would be a defective indicator or wiring from the junction point to the indicator. However, if the trouble appears in both indicators, the possible causes would be the wiring from the junction point to the transducer. It can also occur in the lines from the engine to the transducer.

By connecting the synchro tester to the transducer connector, you can simulate the transducer output signal. (For this test, you will need a locally manufactured adapter cable.) The applicable aircraft TO lists the synchro XMTR settings for a given EPR. If the system checks good, your next step is to perform a leak-check on the EPR pressure lines. From your study of the dial-type EPR system, you should recall that a leak in the engine exhaust pressure line causes a low indication. However, a leak in the inlet pressure line causes a high indication as altitude increases. Should the pressure lines check good, you have eliminated the trouble to a defective transducer.

On most aircraft that have the vertical scale engine instrument systems, the 115-volt AC power to the converter unit is supplied through a circuit breaker. From the converter unit, the power is distributed to the rpm, EGT, and fuel indicating systems. This means that, when the applicable circuit breaker is set, all of the above mentioned indicating systems are operating. So, during your troubleshooting, remember to isolate the system you are checking by pulling the applicable circuit breaker. The EPR system is protected by individual circuit breakers for each indicating system.

Exercises (677):

1. Refer to figure 6-6. What indication would the EPR indicators show if the excitation voltage to the rotor of the transducer synchro were lost? Why?

2. 2. What type of indication would the vertical-scale EPR indicator give if there were a P_{t_2} leak at very high altitude? Why?

678. Identify the test cables required for bench checking vertical-scale engine instrument indicators and also state why the EIS analyzer and converter test set are required for bench checking.

Bench Check. The bench checks of the engine-mounted signal-sensing components are done by following generally the same procedures we discussed in the previous chapters of this volume. As a rule, the same test equipment is used, with slight connector modifications. The wiring diagrams for the connector modifications are found in the applicable aircraft TOs.

The vertical scale engine instrument system indicators are bench checked with the EIS analyzer. However, the test cables supplied with the converter test set must be used together with the test cables supplied with the EIS analyzer to connect the indicators to the tester. Tables of cable usage for these tests are found in the operation and service instructions TO for the EIS analyzer. The tests on the indicator are performed following the step-by-step procedure listed in the same TO.

The converter unit bench check requires both the EIS analyzer and the converter test set. The EIS analyzer is connected to the converter unit. The converter test set is also connected to the converter unit. This is done to monitor the converter outputs to the indicators. Cable-connecting instruction and procedures for performing the test are found in operation and service instructions for the converter test set.

Exercises (678):

1. From what two testers are test cables required to bench check the vertical scale engine indicators on the bench?

2. State why the EIS analyzer and the converter test set are both required to bench check the converter unit.

651

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ANSWERS FOR EXERCISES

CHAPTER 1

References:

600 – 1. Mishandling, improper packaging, and shock.
600 – 2. The type of equipment, along with shipping destinations and storage considerations.
600 – 3. (1) d.
(2) e.
(3) b.
(4) a.
(5) c.
(6) g.

601 – 1. Either of two interchangeable items may be used to replace the other. A suitable substitute may be used in place of the original equipment, but the original equipment will not do the job of the substitute item.
601 – 2. The flanged component that holds the cover glass in place.
601 – 3. Clamp mounting.
601 – 4. Inspect its mount and the area around it for any fault which might be hidden with the unit in place.
601 – 5. Protect it from moisture, dust, and foreign objects.
601 – 6. (1) Pull the system's circuit breakers and hang a danger tag on them, (2) cap or plug the open lines, (3) place a danger tag on the engine's operating controls, and (4) enter all of the necessary information in the next open discrepancy block of the 781A on a red X symbol.

602 – 1. They indicate to the aircrew, at a glance, that flight operations are safe, desirable, or unsafe.
602 – 2. (1) Red for danger areas, (2) green for safe areas, (3) yellow for unsafe or undesirable conditions, and (4) blue for lean fuel mixtures.
602 – 3. To the cover glass directly over the instrument graduations of the scale ranges.
602 – 4. An oil or grease film on the glass.
602 – 5. All instruments that have range markings installed.
602 – 6. To show if the cover glass has shifted.

603 – 1. .020-inch diameter safety wire.
603 – 2. Copper wire. Because it can be easily broken when the equipment is needed.
603 – 3. On screws in a closely spaced or closed pattern like a triangle, square, rectangle, or circle.
603 – 4. The number that a 24-inch long piece of wire will reach.
603 – 5. The wires are twisted together in a right-handed (clockwise) direction with 8 to 10 turns per inch.
603 – 6. Recheck to insure that the sharp ends are bent back and that the safety wire is pulling in the direction that tightens the nuts, bolts, or screws.

604 – 1. Bonding is the electrical connection of two or more conductive surfaces which are not otherwise adequately connected. This is to eliminate any difference in potential.
604 – 2. By removing a small area of the protective finish from the instrument case between the case and the clamp.
604 – 3. By spot cleaning the contact surfaces between the mounting screw and light fixture (if used), between the light fixture and case, and between the instrument panel and nut.
604 – 4. Shock-mounted instruments are bonded to the shock mount, and a bonding jumper is connected from the shock mount to the airplane structure.

605 – 1. When the inspection of the item shows that it could be repaired using standard shop practices and when repair parts are available.
605 – 2. That repairs to most instruments will be limited to those repairs determined necessary by inspection and testing, not complete overhaul.
605 – 3. (1) Inspection of the item, both internally and externally, (2) functionally checking, (3) repair as necessary, and (4) the final functional test.
605 – 4. They are condemned, unless otherwise directed.
605 – 5. When any instrument requires parts and labor equal to 75 percent or more of its original costs, it will normally be condemned.
605 – 6. Because of the hazardous chemicals used in the cleaning of instrument parts, all instrument repair must comply with applicable OSHA standards to insure personal safety.

606 – 1. The gradual chemical or electrochemical attack on a metal by atmosphere, moisture, or other agents.
606 – 2. They should either be replaced or reworked.
606 – 3. To prevent (1) further damage, (2) flaking, and (3) possible lodging in critical areas.
606 – 4. Scraping.
606 – 5. Everyone involved in the building, operational use, or maintenance of aerospace equipment.
606 – 6. Check with your supervisor.
606 – 7. Graphite.
606 – 8. Graphite.
606 – 9. Insure (1) that you have the proper type of footwear and (2) that no metal chips, stones, dirt, sand, or other abrasive material is lodged in your footwear.
606 – 10. Document it in the AFTO Form 781A to insure that qualified personnel assess the damage and take the necessary corrective action.
606 – 11. Cover the surrounding surfaces and/or remove residue from the operation immediately.
606 – 12. Whoever finds it.

CHAPTER 2

607 – 1. The bourdon tube. It is basically a flattened, coiled, metal tube which straightens out when pressure is applied internally.
607 – 2. It maintains a pressure on the gears to eliminate backlash between the sector and pinion gears.
607 – 3. The pressure applied to a direct pressure gage is sensed by a sensing mechanism and is translated into mechanical movement that is transmitted through a linkage arrangement to provide a pointer indication.
607 – 4. Pressure could not be maintained inside it; therefore, it would either provide a low indication or no indication (zero).
607 – 5. Differential pressure.

608 – 1. Differential pressure.

608 – 2. Atmospheric pressure is applied to one side of the diaphragm, and the source pressure is applied to the other side.
608 – 3. Through rocker arm lever.

609 – 1. Absolute pressure.
609 – 2. The aneroid is sealed; the diaphragm has an opening to receive pressure.

610 – 1. Absolute and differential.
610 – 2. The bellows is more rugged than either the diaphragm or aneroid and is therefore less apt to be damanged by rapid pressure changes.
610 – 3. When one of the bellows is connected to a source to be measured and the other is sealed, the instrument is designed to measure absolute pressure.
610 – 4. The type of pressure and the range (amount) of the pressure to be measured.

611 – 1. Checking the condition of the cover glass, placement and condition of range and slippage marks, security of mounting, and general overall condition. Look for fluid or vapors inside the cover glass.
611 – 2. Replace the gage with a known good gage.
611 – 3. Bleeding the system.

612 – 1. As a standard for testing pressure instruments.
612 – 2. 5 to 10,000 psi.
612 – 3. You must clean the tester and refill it with glycerine to prevent any oil from entering the oxygen components.
612 – 4. By positioning the small displacement piston as the small star valve is turned.
612 – 5. You must prevent excessive pressure from entering the gage under test.

613 – 1. The scale error check.
613 – 2. Curve error.
613 – 3. Range error.

614 – 1. The radius of rotation must be changed.
614 – 2. The starting angle must be adjusted.
614 – 3. Making certain the pointer is set on zero.
614 – 4. When one adjustment affects the other, alternately adjust the curve and range error until the gage is within tolerance.

615 – 1. Friction error.
615 – 2. Position error.
615 – 3. Position error.

CHAPTER 3

616 – 1. (1) d.
    (2) g.
    (3) e.
    (4) b.
    (5) f.
    (6) h.
    (7) c.

617 – 1. The angular position of the rotor in relation to the stator coils.
617 – 2. 26-volt, 400-Hz, single-phase AC.
617 – 3. No. Because when the rotors of both synchro units are aligned, identical voltage will be inducted into both stators. With identical induction, no difference in potential exists and no current will flow.
617 – 4. When the rotor is parallel to the stator winding.
617 – 5. By the movement of the mechanical-sensing device.
617 – 6. A magnetic field.
617 – 7. The magnetic fields in the stator coils.
617 – 8. The indicator pointer will remain at the last indication. The reason is that no pointer pulloff mechanism (hairspring) is installed in the indicator.

618 – 1. Security of mounting, condition of shock mounts, evidence of leakage, and proper safetying.
618 – 2. To consult the applicable aircraft technical order.
618 – 3. Qualified personnel only.

619 – 1. The synchro instrument field test set.
619 – 2. Either a 115-volt, or a 26-volt, 400-Hz, single-phase, AC power source.
619 – 3. Approximately 10°.
619 – 4. (1) e, i.
    (2) h.
    (3) n.
    (4) c, f.
    (5) l.
    (6) a, c.
    (7) m.
    (8) d, j.
    (9) n.
    (10) b.
    (11) c.

620 – 1. In the technical order for the indicator.
620 – 2. To see if the indicator pointer has slipped.
620 – 3. The CAL position.

621 – 1. To dampen movement of the metering vane and return the vane to the NO FLOW position when fuel flow through the transmitter stops.
621 – 2. A magetic coupling device.
621 – 3. The moveable vane becomes stuck.
621 – 4. An irregularly-shaped sector gear.
621 – 5. Provide an accurate indication on a nonlinear dial indicator.
621 – 6. To operate a single-synchro indicator.
621 – 7. The linear synchro of the transmitter.
621 – 8. The range switch.
621 – 9. Adjust the output of the linear synchro to exactly zero when the transmitter is at a no-flow state.

622 – 1. (1) d.
    (2) h.
    (3) b.
    (4) c, g, i.
    (5) a, j, m.
    (6) f.
    (7) e.

623 – 1. So that the signal applied to the totalizer indicator will be the sum of all of the transmitters' signals.
623 – 2. When the induction motor runs, it drives a gear train connected to the linear synchro rotor.
623 – 3. When there is no difference
623 – 4. (1) d.
    (2) f.
    (3) b, c.
    (4) a, g.

624 – 1. You must check components for security of mounting, overall condition of components and wiring, and transmitter for leakage.
624 – 2. To run the engine.
624 – 3. The No 1 indicator would remain at its last indication when the wire opened. The totalizer indication would remain normal.
624 – 4. The totalizer indicator would show the last indication at the time the wire was opened. Pin C is the power input connection to the indicator. With no power connected to the amplifier or the fixed phase of the induction motor, the indicator would not operate.
624 – 5. To run the engines one at a time and compare the readings on the individual engine indicators to the increase shown by the totalizer as each engine started.

625 – 1. The term "second harmonic" means that the shape of the sine wave is changed so as to effectively double the basic frequency.
625 – 2. In the second-harmonic fuel flow system, the rotors of the synchros are permanent magnets.
625 – 3. The second-harmonic type transmitter measures the amount of fuel flow by how much its swirling deflects a turbine.
625 – 4. A second restraining spring on the turbine shaft is used to increase the resistance of the turbine to further deflection.
625 – 5. It provides power to drive the transmitter impeller motor at a constant speed.
625 – 6. A transformer energized potentiometer within the individual engine indicator.

625 – 7. It operates a solenoid used to break contact between the brush and potentiometer windings for the totalizer signal. This is to eliminate friction.
625 – 8. The servo-driven gear train that positions the pointer of the totalizer indicator also positions the brush arm of a followup potentiometer, which provides an opposing voltage to null out the signal from the individual indicators.

626 – 1. (1) Close the fuel shutoff valves for the affected engine, pull the circuit breakers for the valves and the affected fuel flow system, remove all electrical power from the aircraft, and place danger tags on circuit breakers, battery switches, external power receptacles, and engine controls.
626 – 2. They should be lubricated with oil and installed on the fittings which go in the inlet and outlet parts in the transmitter.
626 – 3. Fuel flow transmitters normally have an arrow stamped on the case to show direction of fuel flow. Using this arrow, you can determine which line connects to which port in the transmitter.
626 – 4. It eliminates any difference in potential between the power supply and adjacent units. It also prevents the power supply from inducing noise in the aircraft radios and interphone systems.

627 – 1. The common synchro fuel flow tester requires 26-volt, 400Hz, single-phase power. The tester for the second-harmonic system requires 115-volt, 400 Hz, single-phase, and 28-volt DC power.
627 – 2. To supply three calibrated AC signal voltages for testing the total flow system on the aircraft.
627 – 3. The linear indicator on the common synchro fuel flow tester is used as a total fuel flow indicator when testing the total fuel flow system on the aircraft. On the tester for the second-harmonic type system, the linear indicator is used to check the output voltage of individual engine indicators which have a signal generating section for a total fuel flow indicator.
627 – 4. The second-harmonic type.
627 – 5. To balance the discriminator circuit so that a midscale reading will be obtained at null conditions.
627 – 6. (1) c, d, k.
(2) f.
(3) a.
(4) b, i.
(5) g.
(6) h.
(7) l.
(8) b.
(9) e.
(10) c, j.

628 – 1. Fuel flow transmitter. Because the necessary flow stand is not available. It is only authorized for depot facilities.
628 – 2. To the degree setting listed in the calibration chart for the indicator you are checking.
628 – 3. To the numerical settings of the linear transmitter switch.
628 – 4. Insure that the correct polarity is observed when connecting power to the power input binding posts of the tester.

629 – 1. Because the dynamometer meter movement can measure AC current without a rectifier circuit.
629 – 2. The D'Arsonval meter movement uses a permanent magnet; the dynamometer meter movement uses electromagnets to create a magnetic field.
629 – 3. The interaction of thermomagnetic fields created by current flowing through the moving and fixed coils.
629 – 4. The variable reluctance pressure transmitter operates on the principle of changing the inductance of the fixed coils. The induction change is accomplished by varying the reluctance to the magnetic lines of force surrounding the coils.
629 – 5. The armature moving inside the coils causes the inductance of the coils to change. The armature is made of a high permeability material. When the armature is moved inside the coils, it offers a lower path of reluctance to the magnetic lines of force around the coils than does the air core.

630 – 1. In series.
630 – 2. Balanced.
630 – 3. Unbalanced condition. An inductance change in either coil or the transmitter will cause the bridge circuit to become unbalanced.

631 – 1. The same as for the synchro system.
631 – 2. An engine runup.
631 – 3. High and low indications.
631 – 4. (1) b, e, f, or g.
(2) b, e, f, g or i.
(3) a, b, f or i.
(4) a, b, f or h.
(5) i.

632 – 1. TTU–26/E test set.
632 – 2. Checking the power input to the test set.
632 – 3. Percentage deflection switch.
632 – 4. from 0 to 100 percent.
632 – 5. A pressure standard such as the deadweight tester.
632 – 6. Adjust the transmitter.

CHAPTER 4

633 – 1. By comparing the exhaust pressure to the inlet pressure.
633 – 2. Pt$_2$ is engine inlet pressure, and Pt$_7$ is exhaust pressure.
633 – 3. The EPR transducer converts mechanical motion to an electrical signal and sends it to the indicator, where it is displayed as units of EPR.
633 – 4. The EPR transducer servoloop consists of an error-signal sensing element (variable capacitor or E-core transformer), a two-stage amplifier and discriminator, and a motor to position the two synchros and the balance mechanism fulcrum carriage or the outer plates of the capacitor to cancel the input signal.
633 – 5. To divide each increment of the main dial into 10 parts for a more accurate reading.

634 – 1. 115-volt, 400-Hz, single-phase, AC power.
634 – 2. To provide the excitation voltage to the rotors of the system synchros.
634 – 3. The bottom secondary winding of transformer T1.

635 – 1. An increase or decrease in engine pressures, causing the center plate of capacitor C5 to move from its center position.
635 – 2. Class A.
635 – 3. At cutoff.
635 – 4. The phase relationship of the sensed signal to system applied voltage (in phase or 180° out of phase).
635 – 5. A positive signal.
635 – 6. When the center plate is centered between the two outer plates.
635 – 7. To provide a damping feedback signal to the grid of the first-stage amplifier.
635 – 8. The motor control phase is 180° out of phase with the voltage of the fixed phase; current in the control phase will lead the current of the fixed phase by approximately 90°.

636 – 1. To insure that there is no interference between the pneumatic tubing and the transducer mounting rack.
636 – 2. Prior to entering the intake to inspect a Pt$_2$ probe, remove everything from your pockets. You do this to insure that you do not accidentally drop something that could be ingested by and cause damage to the engine.
636 – 3. Disconnect the tubing from the transducer and from the transducer end-~~transducer~~. Use low pressure and clean, dry air to blow the tubing out.
636 – 4. For accurate EPR indications computed from the flight manual for your aircraft to existing conditions.

637 – 1. The same as at the time when the wire opened.
637 – 2. If pin 1 opened on tube JAN 5687, only the bottom half of the tube would conduct. The top half would not. In this case, the indicator would show an increase in EPR but would not move downscale.
637 – 3. The EPR indiator would be incoperative because system power would be lost.

638 – 1. To provide regulated pitot pressures and static pressures.
638 – 2. Front panel.
638 – 3. Front panel.

638 – 4. Aircraft pneumatic instruments, air data systems, flight instruments, and other equipment.

638 – 5. 115 volts, 400 Hz, single phase.

638 – 6. 3, 97.

638 – 7. −1,500; 80,000; ±. 15; 31.5

638 – 8. 50, 1000, ± 1.5 knots; 0.12, 73.5.

639 – 1. (1) o.
(2) g.
(3) x.
(4) n.
(5) f.
(6) t.
(7) s.
(8) e.
(9) m.
(10) w.
(11) d.
(12) r.
(13) c.
(14) l.
(15) b.
(16) v.
(17) a.
(18) p.
(19) i.

639 – 2. (1) p, v.
(2) j.
(3) y.
(4) i, u, v.
(5) h.
(6) g, o, v.
(7) n.
(8) f.
(9) t.
(10) x.
(11) e.
(12) m.
(13) s.
(14) d.
(15) c.
(16) l.
(17) r.
(18) b, k.
(19) w.
(20) a, k.

640 – 1. To visually inspect the system (and repair any discrepancies found).

640 – 2. The static and pitot vent valves must be closed (fully cw).

640 – 3. Five turns.

640 – 4. To the center of their range.

640 – 5. To flex the internal diaphragms, lubricate moving parts, and insures that the test set is ready for use.

640 – 6. After the warmup and cycling of the test set.

640 – 7. The pitot pressure hose of the TTU–205 is connected to the exhaust pressure (Pt_7) lines of the EPR system, and static pressure hose is connected to the inlet (Pt_2) lines.

641 – 1. The accuracy of the indicator must be verified by the local PMEL.

641 – 2. The leak test and the scale error test.

CHAPTER 5

642 – 1. On the accessory section of the engine for which it is measuring the rpm.

642 – 2. Stationary, three-phase, and wye-connected.

642 – 3. A permanent magnet rotor with either two or four poles.

642 – 4. The tachometer drive of the engine accessory section.

642 – 5. The two-pole rotor is magnetized so that the poles are 180° apart (directly opposite each other), and the magnetic poles of the four-pole rotor are placed every 90°.

642 – 6. One.

642 – 7. A 3-phase, AC voltage.

642 – 8. Because jet engine rpm is extremely high, compared to reciprocating engines.

642 – 9. Induction motors, synchronous motors.

"642 – 10." The types of rotor used in the motors differs.

643 – 1. The speed at which the generator shaft rotates.

643 – 2. The spring restrains the pointer shaft so that the shaft moves only until the spring opposition equals the torque produced on the shaft by the magnetic drag assembly.

643 – 3. The frequency output of the tachometer generator.

643 – 4. To permit the rotor to turn into synchronization with the rotating magnetic field before the shaft picks up any load.

643 – 5. Hysteresis disk.

644 – 1. Checking the indicator for security of mounting, condition and proper placement of the range markings, and overall condition.

644 – 2. You check to make sure the indicator starts smoothly and follows the rpm changes of the engine smoothly and accurately.

644 – 3. (1) d or f.
(2) a, b or f.
(3) b or f.
(4) b.
(5) a.
(6) b.

645 – 1. (1) p.
(2) o.
(3) h.
(4) c.
(5) n.
(6) d.
(7) m.
(8) i
(9) e.
(10) l.
(11) b.
(12) g.
(13) k.

646 – 1. Thermocouple principle: When two unlike metals are fused together and then heated, an electromotive force is generated.

646 – 2. Chromel-alumel thermocouples produce the amount of electromotive force necessary for the high-temperature ranges of jet engines.

646 – 3. The gasket-type thermocouple, mounted under the spark plug of the hottest running cylinder.

646 – 4. In the exhaust section of jet engines.

646 – 5. The use of a temperature compensator to maintain an accurate reference point.

647 – 1. Size of wire, length, connections, and resistance value to within ± 0.01 ohm.

647 – 2. The temperature to which the leads are exposed and the amount of lead resistance required for system operation.

647 – 3. Cutting a thermocouple lead will change its resistance, and any change in resistance will make the temperature indication inaccurate.

647 – 4. By using an adjustable resistor in the negative lead.

647 – 5. By checking the stamp resistance number on the back of the indicator.

648 – 1. (1) b.
(2) e, j.
(3) a, h.
(4) d, k.
(5) i.

648 – 2. Exhaust gas temperature systems.

648 – 3. The servomechanism indicator responds faster than the D'Arsonval movement thermocouple indicator to temperature changes at the thermocouples. The indicator does not require ambient temperature adjustments, and thermocouple lead resistance is not critical to the operation of the indicator.

648 – 4. Because the cold junction reference temperature is maintained constant by the cold junction compensator, regardless of ambient temperature variations.

648 – 5. In parallel with the indicator. The thermocouple output millivolt signal will be the average output of all the thermocouples. This

will cause the indicator to show the average exhaust gas temperature.

649 − 1. The iron lead.
649 − 2. The indicator will read 180°, since the indicator is corrected for ambient temperature.
649 − 3. The output of the thermocouples is compared in a bridge circuit to the reference voltage of the rebalance potentiometer wiper. Any difference between the two is the error signal.
649 − 4. The servomotor drives and positions the pointer. The mechanical linkage also repositions the wiper of the rebalance potentiometer until the reference voltage is equal to the voltage output of the thermocouples.
649 − 5. The resistance of the thermocouple circuit.

650 − 1. You check the indicator for condition of the cover glass, proper placement of range markings, and temperature indications consistent with known temperatures.
650 − 2. The aircraft should be turned into the wind to prevent possible abnormal temperature indications.
650 − 3. (1) f, j.
    (2) a, f, i, j.
    (3) b, e.
    (4) b, e, g.
    (5) b, c.
    (6) d, i.
    (7) e.

651 − 1. (1) c, f.
    (2) i, l.
    (3) n.
    (4) d, j.
    (5) h.
    (6) h.
    (7) b, g, k.
    (8) m.
    (9) o.

651 − 2. By using heater probes which heat the aircraft thermocouples to various temperatures; then the aircraft temperature indicator reading is compared with the Jetcal tester reading.
651 − 3. Galvanometer.
651 − 4. 115-volt power. Both of the BH112 models will operate on any frequency between 50 and 400 Hz. The H119 uses 400 Hz only.
651 − 5. Calibrate indicators and check resistance, insulation, thermal switches, and engine rmp.
651 − 6. 900° C.

652 − 1. The indicator accuracy check, circuit insulation resistance check, circuit resistance check, and thermocouple response check.
652 − 2. It provides a means of self-testing the Jetcal calibration.
652 − 3. Fully counterclockwise.
652 − 4. Connect one lead of insulation check adapter to one of the aircraft leads and the other adapter lead to ground.
652 − 5. Each lead of the resistance check adapter is connected to a lead of the aircraft EGT circuit after the indicator has been removed.
652 − 6. Check, clean, and secure all connections in the system. Also use a Wheatstone bridge to make an exact measurement of the circuit resistance.
652 − 7. The rheostat dial settings multiplied by the setting of the MULTIPLY BY dial.
652 − 8. It shows if each thermocouple is generating an output when heat is supplied.
652 − 9. It permits all of the thermocouple heater probes to be heated at the same time.
652 − 10. It provides a means for selecting the Jetcal tester or the aircraft indicator for reading the thermocouple temperature.

653 − 1. To measure the temperature of oil, coolant, and carburetor air.
653 − 2. Of the three typical resistance temperature bulbs, one type is long, one is short, and one is disc-shaped.
653 − 3. The disc-shaped resistance temperature bulb. Because of the physical structure.
653 − 4. A nickel winding. Nickel is used because its resistance is greatly affected by changes in temperature.
653 − 5. It allows the resistance thermometer indicator to be used on either a 12-volt or a 28-volt electrical system.
653 − 6. To eliminate changes in the indication of temperature on the indicator caused by changes in the voltage supply.
653 − 7. The ratiometer movement uses two coils; the D'Arsonval movement uses one coil.
653 − 8. It eliminates the need for hairsprings.

654 − 1. The resistance bulb must be checked for security of mounting, obvious external damage, and proper safetying.
654 − 2. Apply power to the system and check to insure that the temperature indications are consistent with known temperatures.
654 − 3. (1) b, c, d, e, f.
    (2) b, f, g.
    (3) a, b, d, f.
    (4) a, b, f.

654 − 4. Both single and dual indicators.
654 − 5. In the TO applicable to the indicator being bench checked.
654 − 6. No. Either gage connected alone would read correctly; but if both gages were connected, the two resistances in parallel would reduce the resistances to one-half, and the increased current would make both gages read off-scale high.

CHAPTER 6

656 − 2. Two. One generator to measure the speed of the low-speed compressor of the engine, and one to measure the speed of the high-speed compressor.
656 − 2. 3-phase AC voltage.

656 − 1. Chromel; alumel.
656 − 2. A small DC voltage (millivolts) which is proportional to the average exhaust gas temperature.
656 − 3. The vertical-scale system EGT thermocouple probes are dual element thermocouples, identical in construction and similar in appearance to other dual thermocouples.

657 − 1. A synchro-signal output. The angular position of the synchro rotor is proportional to the mass rate of fuel flow.
657 − 2. 115-volt, 400-Hz, single phase, AC power.

658 − 1. Inductive bridge circuit.
658 − 2. The conventional transducer uses tubes and a capacitive bridge or inductive bridge circuit; the vertical-scale transducer uses trandsistors an an inductive bridge circuit only.

659 − 21. The rpm channel boards receive the variable AC voltage and frequency signal output from the tachometer generators and converts the signals to 400-Hz AC signals to drive the rpm indicator servomotors.
659 − 2. The frequency output of the generator.

660 − 1. The EGT channel boards recieve DC millivolt signals from the thermocouples and convert them to 400-Hz AC signals, which drive the EGT indicator servomotors.

661 − 1. The fuel flow channel boards receive the control transformer signals from the fuel flow indicators. The signals are amplified and discriminated to drive the indicator's servomotors.

662 − 1. There is a fuse to protect each circuit that goes through the converter unit, and the connectors provide a means for connecting the signal-sensing components and the vertical-scale indicators to the converter unit.

663 − 1. The rpm of the engine's low-speed compressor.
663 − 2. They furnish servoloop rebalance voltage back to the rpm channel boards in the converter unit.

664 − 1. The calibrated scale is the only difference between the vertical-scale EGT and rpm indicators.
665 − 1. the fuel flow indicators incorporate a control transformer to a rebalance the servoloop instead of variable potentiometers.

666 − 1. The EPR indicator contains the signal amplifiers of the indicating system servoloops. Therefore, the servoloops are contained within the indicator, making it unnecessary for the EPR signals to pass through the converter unit.

667 – 1. (1) c, d, e, l.
(2) n.
(3) f, j.
(4) e.
(5) b, h.
(6) a, k.
(7) g.
(8) m.

668 – 1. (1) d, i.
(2) c, m.
(3) h, k.
(4) e.
(5) b, g.
(6) f, j.
(7) a, l.

669 – 1. When the rotor is perpendicular to the stator's magnetic field.
669 – 2. Indicator control transformer.
669 – 3. (1) a, c, f, h, i.
(2) e.
(3) g.
(4) b.

670 – 1. (1) h.
(2) e.
(3) j.
(4) i.
(5) g.

671 – 1. Security of mounting, cover glass condition, internal lighting operation, and condition and proper placement of range markings.
671 – 2. To insure that the word ''OFF'' disappears from view when power is applied to the system.

672 – 1. (1) f.
(2) g.
(3) a, m.
(4) b, h.
(5) i.
(6) d, k.
(7) p.
(8) c.
(9) j.
(10) o.
(11) e.

673 – 1. (1) d.
(2) n.
(3) c, o.
(4) a, j.
(5) a, p.
(6) a, t.
(7) k.
(8) g, r.
(9) b.
(10) l.
(11) f.
(12) m, q.
(13) e.

674 – 1. No rpm indication and fluctuations.
674 – 2. The TTU 27/E tachometer tester.
674 – 3. The pilot's indicator would drive off-scale high. Because only the converter DC signal would be present to the modulator. Consequently, the motor would drive upscale. Since no feedback voltage could reach the modulator to rebalance the servoloop, the motor would continuously drive in the same direction. The flight engineer's indicator would be normal.

675 – 1. Low indication.
675 – 2. Defective channel board.

676 – 1. The pilot's indicator would show the word ''OFF'' at the top of the tape. Because, with no signal input to the servoloop, the servomotor would not be energized. The spiral spring then would drive the gear train backward, causing the world ''OFF'' to appear.

677 – 1. Both the pilot's and flight engineer's indicators would show the world ''OFF'' at the top of the tapes. With no excitation voltage to the transducer rotor, no signal would be transmitted from this synchro to the indicator synchro. Consequently, no error signals would be induced into the rotor of the indicator synchro. With no error signal to the amplifier, the servomotor could not be energized. The spiral spring in the tape drum would turn the gear train backward, exposing the word ''OFF'' at the top of the tapes.
677 – 2. A low indication. A Pt_7 leak will give a low indication on the ground or at any altitude.

678 – 1. The test cables from the converter test set are used in conjunction with the cables from the EIS analyzer.
678 – 2. The EIS analyzer supplies input signals to the converter unit, and the converter test set monitors the output signals from the converter unit.

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STOP - 1. MATCH ANSWER SHEET TO THIS EXERCISE NUMBER.
2. USE NUMBER 2 PENCIL ONLY.

EXTENSION COURSE INSTITUTE
VOLUME REVIEW EXERCISE

32551 04 23

MAINTENANCE FUNDAMENTALS AND ENGINE INSTRUMENTS

Carefully read the following:

DO's:

1. Check the "course," "volume," and "form" numbers from the answer sheet address tab against the "VRE answer sheet identification number" in the righthand column of the shipping list. If numbers do not match, return the answer sheet and the shipping list to ECI immediately with a note of explanation.
2. Note that item numbers on answer sheet are sequential in each column.
3. Use a medium sharp #2 black lead pencil for marking answer sheet .
4. Write the correct answer in the margin at the left of the item. (When you review for the course examination, you can cover your answers with a strip of paper and then check your review answers against your original choices.) After you are sure of your answers, transfer them to the answer sheet. If you have to change an answer on the answer sheet, be sure that the erasure is complete. Use a clean eraser. But try to avoid any erasure on the answer sheet if at all possible.
5. Take action to return entire answer sheet to ECI.
6. Keep Volume Review Exercise booklet for review and reference.
7. If mandatorily enrolled student, process questions or comments through your unit trainer or OJT supervisor. If voluntarily enrolled student, send questions or comments to ECI on ECI Form 17.

DON'Ts:

1. Don't use answer sheets other than one furnished specifically for each review exercise.
2. Don't mark on the answer sheet except to fill in marking blocks. Double marks or excessive markings which overflow marking blocks will register as errors.
3. Don't fold, spindle, staple, tape, or mutilate the answer sheet.
4. Don't use ink or any marking other than a #2 black lead pencil.

NOTE: NUMBERED LEARNING OBJECTIVE REFERENCES ARE USED ON THE VOLUME REVIEW EXERCISE. In parenthesis after each item number on the VRE is the Learning Objective Number where the answer to that item can be located. When answering the items on the VRE, refer to the Learning Objectives indicated by these Numbers. The VRE results will be sent to you on a postcard which will list the actual VRE items you missed. Go to the VRE booklet and locate the Learning Objective Numbers for the items missed. Go to the text and carefully review the areas covered by these references. Review the entire VRE again before you take the closed-book Course Examination.

MULTIPLE CHOICE

Note to Student: Consider all choices carefully and select the best answer to each question.

1. (600) Which types of containers and packaging are normally intended to be reused?

   a. Level A and level B.
   b. TPO and commercial.
   c. Level C and TPO.
   d. Level B and level C.

2. (600) How should a fuel flow transmitter be prepared for shipment on a military aircraft?

   a. It should be drained and tagged with an AFTO Form 350 and a red tag.
   b. It should be tagged, level-A packaged, and sealed in the container.
   c. It should be drained and flushed, have all openings sealed, be packaged in a TPO container, and be tagged and labeled.
   d. It should have all openings sealed, be level-D packaged, be properly identified, and marked with warning labels.

3. (601) A replacement part which exceeds the requirements of the original part is referred to as

   a. an interchangeable item.
   b. a substitute item.
   c. a preferred item.
   d. a like item.

4. (601) What should you do before installing any instrument?

   a. Bench check the instrument.
   b. Functionally check the instrument.
   c. Remove power from the aircraft.
   d. Inspect the mounting area.

5. (601) If you are unable to finish a job on an electrical system, what should you do to prevent accidental short circuits?

   a. Remove power from the aircraft.
   b. Document the status of the system on the AFTO Form 781A.
   c. Pull the circuit breakers and cover the open ends of loose connections.
   d. Pull the circuit breakers and tag them with AFTO Forms 350.

6. (602) Why should an instrument specialist frequently use a -1 TO (flight manual)?

   a. To identify other applicable technical orders.
   b. To determine proper placement of range marks.
   c. To learn precise maintenance procedures.
   d. To code maintenance data collection forms.

7. (602) When do instruments with range markings on a square cover glass require a slippage mark?

   a. When there is a possibility the cover glass could shift.
   b. When the instrument must be used during flight.
   c. Anytime there are range markings on the glass.
   d. Anytime red range markings are used.

8. (602) How are range markings applied?

   a. They are coated with rubber cement and immediately stuck on the cover glass.
   b. They are cut to size, the backing material is removed, and they are pressed onto the glass over the graduation marks.
   c. They are cut to size, soaked in solvent, placed on the cover glass, and sealed with anti-tamper compound.
   d. They are cut to size, glued to the bezel, and sealed with anti-tamper compound.

9. (603) How do you determine the correct size of safety wire to use if the TO does not provide this information?

   a. You always use .032 for hardware and .020 for electrical connectors.
   b. You use the largest size that will fit in the hole.
   c. You use .032 for single-strand safetying and .020 for double-strand safetying.
   d. You use a safety wire which will fill 3/4 of the hole.

10. (603) When may you use the single-strand method of safetying?

   a. When the screws, nuts, or bolts are in a closely spaced or closed pattern.
   b. When there are more than 10 items to be safetied.
   c. When .045 diameter safety wire is used.
   d. When lock washers are used to reinforce the safety wire.

11. (603) Electrical connectors must be safetied with

   a. .020 diameter wire using the single-strand method.
   b. .020 diameter wire using the double-strand method.
   c. .032 diameter wire using the single-strand method.
   d. .032 diameter wire using the double-strand method.

12. (604) Why are instruments bonded?

   a. To eliminate any difference in case potential.
   b. To provide a system ground so the indicator will operate.
   c. To permit the installation of a bezel mount.
   d. To insulate the instrument from eddy currents.

13. (604) Unless otherwise instructed by technical data, all electrically operated instruments should be bonded to obtain a low resistance of

a. 10 ohms.	c. .1 ohm.
b. 1 ohm.	d. .01 ohm.

14. (605) Under what instrument concept are repairs to instruments limited to those repairs determined necessary by inspection and testing?

a. Military repair criteria.
b. Air Force readiness practices.
c. Selective repair.
d. Standard shop practices.

15. (605) How do you assist AFLC in increasing the reliability of instruments?

a. By reporting instrument malfunctions through the MDC system.
b. By repairing defective instruments in your shop.
c. By functionally checking instrument prior to installation in the aircraft.
d. By properly packaging instruments prior to shipment.

16. (605) The USAF concept of instrument repair requires

a. a complete overhaul of the instrument.
b. local manufacture of needed parts.
c. a check of the instrument for unaccomplished TCTOs.
d. condemnation of all corroded parts.

17. (605) What environmental condition is necessary in order to maintain close tolerances when repairing instruments?

a. Cleanliness.	c. Controlled humidity.
b. A controlled temperature.	d. Noise level.

18. (606) What factor determines if a corroded part can be cleaned and used?

a. The type of corrosion.
b. The value of the part.
c. The availability of a replacement part.
d. The function of the part.

19. (606) Which of the following parts will be replaced if corroded?

a. Wire, washers, bearings, and pivots.
b. Switches, brushes, and slip rings.
c. Housings, commutators, and electrical contacts.
d. Mounts, tubes, and pulleys.

20. (606) Which type of lubricant should not be used on metal surfaces, especially in hot, moist environments?

a. Heavy grease.
b. Heavy oil.
c. Graphite.
d. Hydraulic fluid.

21. (606) What should you do about frequent, severe, or unusual corrosion that you find on an aircraft?

a. Remove the corrosion and rework the part.
b. Remove the corrosion and treat the area.
c. Leave it as is for the corrosion control specialist to find.
d. Report it to the corrosion control supervisor or specialist.

22. (607) When internal pressure is applied to the curved Bourdon tube, the tube will

a. straighten out.
b. collapse.
c. twist.
d. coil.

23. (607) When a Bourdon tube is connected to a pressure source and the case surrounding the tube is vented to atmospheric pressure, the gage will measure

a. absolute pressure.
b. atmospheric pressure.
c. differential pressure.
d. absolute or differential pressure.

24. (608) Diaphragm-sensing mechanisms are used in direct-reading pressure gages that measure

a. large absolute pressure changes.
b. small absolute pressure changes.
c. large differential pressure changes.
d. small differential pressure changes.

25. (608) For a diaphragm to expand, the applied

a. pressure must increase.
b. pressure must decrease.
c. vacuum must increase.
d. vacuum must decrease.

26. (609) The pressure-sensing aneroid

a. is a pressurized capsule.
b. has an opening at the base to receive pressure.
c. expands as pressure is applied to its interior.
d. consists of two thin metal corrugated discs soldered together.

27. (609) The aneroid is sealed at

a. sea level.
b. near vacuum.
c. 60 inches Hg.
d. barometric pressure.

28. (610) A sensing mechanism that can be used in direct-reading pressure gages to measure either absolute or differential pressure is the

a. aneroid.
b. diaphragm.
c. dual bellows.
d. Bourdon tube.

29. (610) Which of the pressure-sensing devices is least likely to be damaged from the stress and strain of rapid pressure changes?

a. Aneroid.
b. Bellows.
c. Diaphragm.
d. Bench Tester.

30. (611) How can you safely bleed the pressure off a hydraulic system?

a. remove aircraft power.
b. Turn the hydraulic pumps off.
c. Cycle the brakes, flight controls, etc.
d. Pull the circuit breakers for the pumps and valves.

31. (612) What range of pressures can you obtain when using the low-pressure piston in the deadweight tester?

a. 1 to 1,000 psi.
b. 5 to 2,000 psi.
c. 10 to 5,000 psi.
d. 25 to 10,000 psi.

32. (612) The deadweight tester must be cleaned and refilled with glycerin before testing

a. hydraulic pressure gages.
b. oxygen pressure gages.
c. oil pressure gages.
d. vacuum gages.

33. (613) If pointer indications at both ends of the dial are correct but errors occur in the middle range, what type of error does the instrument have?

a. Scale error.
b. Curve error.
c. Range error.
d. Friction error.

34. (614) To correct range error in a direct reading gage, the repairman will

a. adjust the starting angle.
b. install a larger sector gear.
c. change the radius of rotation.
d. bend the tail of the Bourdon tube.

35. (614) What is always the first step in the calibration of a direct-pressure gage?

a. Adjust the range.
b. Set the pointer to zero.
c. Adjust the starting angle.
d. Lubricate the sensing element.

36. (615) What error is present in a direct-reading pressure gage when the indications change as the gage is rotated about its longitudinal axis?

a. Friction error.
b. Position error.
c. Range error.
d. Curve error.

37. (616) The two main sections of a synchro transmitter are the

a. pressure-measuring and synchro sections.
b. pressure-link and mechanical-sensing sections.
c. Bourdon tube and electrical-connector sections.
d. mechanical-sensing and electrical-transmitting sections.

38. (616) In the synchro transmitter, why is a hairspring attached to the rotor shaft?

a. To conduct current to the rotor.
b. To pick off signals from the rotor.
c. To eliminate backlash in the gears.
d. To restrain rotor movement.

39. (617) Applied pressure to a synchro transmitter is first sensed by the

a. mechanical-sensing mechanism.
b. drag link assembly.
c. synchro unit.
d. sector gear.

40. (618) When inspecting a synchro system, the indicator is inspected for general overall condition, security of mounting, condition of the cover glass, and

a. proper safetying.
b. proper placement on the panel and illumination.
c. internal parts for lubrication.
d. condition and placement of range markings.

41. (619) What part of the synchro field test set is used to bench check a synchro transmitter?

a. Synchro indicater test circuit.
b. Synchro transmitter.
c. Servo circuit.
d. Motor control potentiometer.

42. (620) Which test is performed on a synchro indicator to check for pointer slippage?

a. Electrical zero.
b. Calibration.
c. Range error.
d. Curve error.

43. (620) On the synchro system field tester, in what position must the sync indicator switch be placed to perform the scale error check of the indicator?

a. E-Z.
b. CAL.
c. IND.
d. TRANS.

44. (621) The calibrated spring in a single fuel flow transmitter dampens the

a. synchro rotor movement.
b. bypass relief valve.
c. permanent magnet.
d. moveable vane.

45. (622) Signals for the totalizer operation originate in what unit of the multisynchro fuel flow transmitter?

a. Adjustable transformer.
b. Synchro transmitter.
c. Autotransformer.
d. Linear synchro.

46. (623) Which unit of a total fuel flow indicator produces the damping feedback signal?

a. Rate generator.
b. Autotransformer.
c. Adjustable transformer.
d. Induction motor.

47. (623) When the totalizer indicator reaches the proper indication, the signal from the linear synchros of the fuel flow transmitters is cancelled by the indicator

a. adjustable transformer.
b. control transformer.
c. induction motor.
d. linear synchro.

48. (624) How can errors in the fuel flow totalizer system be detected?

a. By bench checking the indicator.
b. By taking resistance measurements.
c. By comparing indications during an engine run.
d. By taking voltage measurements during an engine run.

49. (625) What type of rotor is used in the second-harmonic type fuel flow indicator?

a. Delta wound.
b. Squirrel cage.
c. Permanent magnet.
d. Mechanically positioned.

50. (625) What is the power requirement of the second-harmonic type fuel flow power supply?

a. 28V DC.
b. 26V, 400 Hz, three-phase.
c. 115V, 400 Hz, single-phase.
d. 15 to 24V, 4-cycle, three-phase.

51. (626) What should be your first step in preparing to replace a fuel flow transmitter?

a. Remove power from the aircraft.
b. Close the engine shut-off valves.
c. Install new "O" rings on the fittings.
d. Perform an operational check of the system.

52. (627) What portion of the MO-1 fuel flow is used to check the scale error of total summation fuel flow indicators?

a. Master transmitter.
b. Master indicator.
c. Linear transmitter.
d. Linear indicator.

53. (628) How do you set the desired test point on an individual engine fuel flow indicator when using the common synchro fuel flow tester?

a. Use the knob of the synchro transmitter to set the pointer to the degree setting listed on the calibration chart.
b. Rotate the linear transmitter through its various positions.
c. Stop the counter at the test point given in the calibration chart.
d. Set the voltage control to each of the test points given in the calibration chart for the voltmeter.

54. (628) When checking the cycles-per-second output during a bench check of a fuel flow power supply, what should be your final reading on the counter?

a. 400 Hz.
b. 300 PPH.
c. 360°.
d. 480 cycles.

55. (629) The indicator for a variable reluctance pressure system is basically a

a. DC voltmeter.
b. D'Arsonval meter movement.
c. dynamometer-type, moving coil, AC voltmeter.
d. dynamometer-type AC frequency meter.

56. (629) The inductance of the coils in the variable reluctance pressure transmitter is

a. adjustable in the field.
b. permanently fixed.
c. dependent upon the position of the armature.
d. not affected by the reluctance of the core.

57. (630) When connected, the electrical units of a variable reluctance pressure system form

a. a parallel circuit.
b. an AC bridge circuit.
c. a DC bridge circuit.
d. a capacitance bridge circuit.

58. (631) To perform an operational check of a variable reluctance oil pressure system, you must

a. use the VRP tester.
b. use the deadweight tester.
c. run the engine.
d. use the VRP tester and the deadweight tester.

59. (632) What piece of test equipment is used in conjunction with the TTU 26/E when bench testing a VRP transmitter?

a. Manometer.
b. Deadweight tester.
c. TTU 205 C/E pressure temperature tester.
d. Pneumatic systems test set.

60. (633) The dual bellows assembly in the EPR transducer measures

a. absolute pressure.
b. sea-level pressure.
c. differential pressure.
d. engine exhaust pressure only.

61. (633) The bellows used to sense engine inlet pressure in the EPR system transducer is

a. a dual bellows.
b. an open bellows.
c. a sealed bellows.
d. a collapsed bellows.

62. (634) In the EPR system, the synchros receive 26-volt AC excitation from

a. an inverter.
b. the aircraft power source.
c. an instrument stepdown transformer.
d. transformer T1 in the EPR transducer.

63. (634) The purpose of the rectifier circuits in the EPR transducer is to supply

a. the fixed-phase reference voltages for the velocity generator.
b. the heater voltage for the amplifier and discriminator tubes.
c. grid biasing voltages for the amplifier and discriminator tubes.
d. the operating voltages for the capacitance bridge circuit.

64. (635) The discriminator tube (5687) in the EPR transducer is biased

a. at cut off and conducts only when a negative signal is present.
b. at cut off and conducts only when a positive signal is present.
c. below cut off and conducts continuously to provide a variable control voltage.
d. above cut off and conducts continuously to provide a fixed reference voltage.

65. (636) When installing an EPR transducer, you should

a. reuse the old fittings and seals.
b. safety wire the electrical connector with .032 diameter safety wire.
c. torque the fittings and pneumatic line connections.
d. perform an operational check and leak check using the deadweight tester.

66. (636) When inspecting an EPR system, you should check the P_{t2} probe for

a. evidence of overheating.
b. obstructions.
c. proper alignment.
d. chaffing.

67. (637) What repair action would be necessary if the pointer on the EPR indicator would go upscale but not downscale?

a. Replace the indicator.
b. Replace the transducer.
c. Repair wiring.
d. Clear tubing.

68. (638) What test equipment is used to check an EPR system?

a. MP-1 deadweight tester.
b. GTF-6 capacitance tester.
c. Wheatstone bridge.
d. TTU-205 pressure temperature tester.

69. (639) The ALTITUDE LOW indicator lamp on the front panel of the TTU-205 test set illuminates when the altitude (Ps pressure) is approaching

a. 0.0 inches Hg.
b. 14.7 inches Hg.
c. 32 inches Hg.
d. 45 inches Hg.

70. (640) Where should the AIRSPEED KNOTS control and ALTITUDE X 1000 FEET control on the TTU-205 be set before disconnecting the Ps and P_t hoses?

a. 100 knots and 1000 feet.
b. 50 knots and local field elevation.
c. zero knots and local field elevation.
d. zero knots and sea level.

71. (641) The accuracy of an EPR indicator can be determined during a bench check using which tester?

a. Synchro tester.
b. Capacitance tester.
c. Pneumatic tester.
d. TTU-205.

72. (641) Field shops can

a. do complete bench checks of EPR transducers using the overhaul manual and assigned test equipment.
b. do complete bench checks of EPR transducers using the operation and service manual and mockup.
c. do a functional check of EPR transducers using the operation and service manual and assigned test equipment.
d. do a functional check of EPR transducers using the aircraft technical manual and a mockup.

73. (642) The stator of a tachometer generator is a stationary,

a. single-phase, delta winding.
b. three-phase, delta winding.
c. single-phase, wye winding.
d. three-phase, wye winding.

74. (642) The two major assemblies of a tachometer indicator are the

a. three-phase motor and magnetic drag assembly.
b. single-phase motor and pointer-linkage mechanism.
c. servomotor and magnetic coupling.
d. motor-generator and copper cup.

75. (642) What unit of the tachometer indicator returns the pointers to zero upon engine shutdown?

a. Drag disk.
b. Copper cup.
c. Hairsprings.
d. Magnetic drag assembly.

76. (643) What unit of the synchronous motor tachometer indicator allows the rotor of the motor to synchronize before the rotor shaft picks up any load?

a. Hairspring.
b. Hysteresis disk.
c. Permanent magnet rotor.
d. Magnetic drag assembly.

77. (644) A two-pin connector on a tachometer generator indicates

a. an external ground.
b. an internal ground.
c. a two-phase stator.
d. a four-pole rotor.

78. (645) Which of the following testers is usually used to bench check tachometer components?

a. TTU 23/E.
b. TTU 26/E.
c. TTU 27/E.
d. TTU 205 C/E.

79. (645) When bench checking a four-pole tachometer generator, the desired generator drive speed is reached when the

a. RPM X 1 indicator reads double the desired drive speed.
b. percent RPM indicator reads the desired drive speed.
c. RPM X 1 indicator reads the desired drive speed.
d. RPM X 2 indicator reads the desired drive speed.

80. (646) Which of the following thermocouples is normally used to sense higher temperatures?

a. Iron-alumel.
b. Chromel-alumel.
c. Iron-constantan.
d. Copper-constantan.

81. (647) Each set of AF-type thermocouple leads have fixed resistance value to within ±0.01 ohm,

a. type of wire, size, and length.
b. connections, type of wire, and size.
c. length of wire, type, and connections.
d. size of wire, length, and connections.

82. (648) The bimetallic spring connected to one of the hairsprings in the D'Arsonval meter movement of the thermocouple indicator is used to

a. reduce bearing friction.
b. restrict pointer movement.
c. adjust the indicator for ambient temperature.
d. electrically connect the moving coil to the indicator frame.

83. (648) In most cases, how many thermocouple probes are used when the servomechanism-type indicator is used in the EGT system?

a. Four.
b. Six.
c. Eight.
d. Ten.

84. (649) If the ambient temperature in the cockpit is 25° and the temperature at the thermocouple is 145°, the pointer in the indicator of a D'Arsonvaltype thermocouple system will be at

a. 95°.
b. 120°.
c. 145°.
d. 170°.

85. (650) In addition to those items checked on preflight inspections during a major inspection, the EGT indicators are checked for

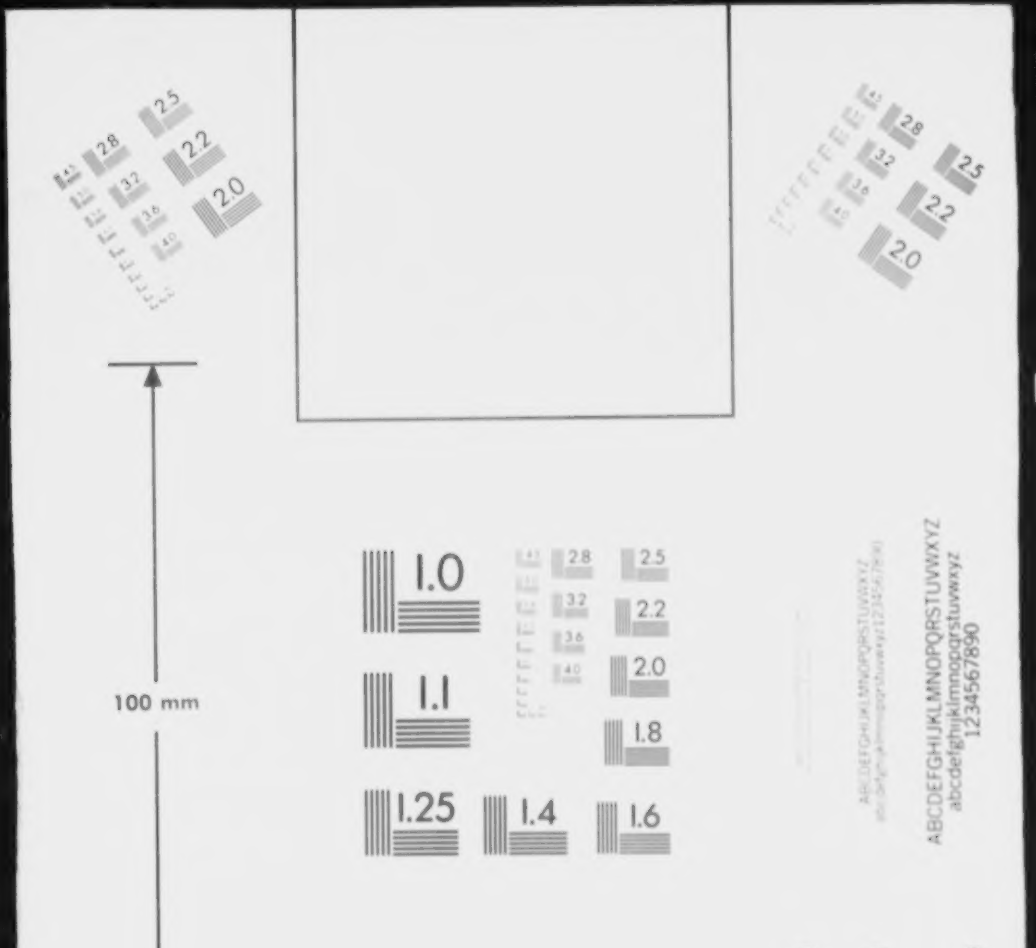
a. external damage.
b. broken cover glass.
c. security of mounting.
d. proper placement of range marks.

86. (650) If the indicator of a servomechanism EGT system indicates too low, what is the most probable cause of trouble?

a. Faulty aircraft engine.
b. Indicator out of calibration.
c. Defective thermocouple circuit.
d. Open lead from the indicator to the thermocouple circuit.

87. (651) Which listed items of test equipment may be safely used to check the resistance of the thermocouple systems?

a. A multimeter, a Jetcal tester, or a Wheatstone bridge.
b. An N-3A thermometer tester, a multimeter, or a Jetcal tester.
c. A Wheatstone Bridge, an N-3A thermometer tester, or a multimeter.
d. A Jetcal tester, a Wheatstone bridge, or an N-3A thermometer tester.


100 mm
A5
1.0
1.1
1.25
1.4
1.6
1.8
2.0
2.2
2.5
2.8
3.2
3.6
4.0
4.5
ABCDEFGHIJKLMNOPQRSTUVWXYZ
abcdefghijklmnopqrstuvwxyz
1234567890
1.0 mm
1.5 mm
2.0 mm

88. (651) You are using the N-3A tester to bench check a chromel-alumel EGT indicator. Why will the tester cause the indicator to read high by the amount that the ambient temperature exceeds 0° C?

a. The tester was designed for use in cold climates.
b. The tester applies millivolts based on 0° C.
c. The tester does not have a compensator.
d. The indicator has a compensator.

89. (651) When using the Jetcal tester, the temperature of the probes should never be allowed to exceed

a. 900° C.	c. 700° C.
b. 800° C.	d. 600° C.

90. (652) In performing the circuit resistance check of a thermocouple system using a Jetcal tester, how are the adapter leads connected to the circuit?

a. One of the adapter leads is connected to ground, and the other is connected to one lead of the aircraft wiring.
b. Each of the adapter leads is connected to one of the aircraft thermocouple leads.
c. One of the adapter leads is connected to an indicator terminal, and the other adapter lead is connected to the aircraft wiring.
d. One of the adapter leads is connected to a thermocouple post, and the other adapter lead is connected to the aircraft wiring.

91. (653) What is the temperature range of the most widely used resistance thermometer indicator?

a. -40° to +120° C.	c. -60° to +140° C.
b. -50° to +130° C.	d. -70° to +150° C.

92. (654) Which of the following describes the operational check of the resistance-type thermometer system?

a. With power on, the indicator reads consistent with known temperatures plus ambient temperature.
b. With power on, the indicator reads consistent with known temperatures.
c. With power off, the indicator reads ambient temperature.
d. With power off, the indicator reads "off-scale hot."

93. (654) You have just finished bench checking a resistance thermometer indicator using the N-3A tester. The indicator did not meet TO specifications. What is your next step?

a. Condemn the indicator and return it to supply.
b. Clean the indicator and check it again.
c. Calibrate the indicator.
d. Repair the indicator.

94. (655) Why are there two tachometer generators on each engine of aircraft on which vertical scale engine instruments are used?

a. Each generator measures the rpm of different engine compressors.
b. In case one fails, there will still be a backup generator operating.
c. Each generator serves either the pilot's or the engineer's rpm indicator.
d. Two generators provide greater accuracy, the indicator shows the averaged RPM of the two generators.

95. (655) The N_2 tachometer indicates the speed of the

a. high-speed compressor.
b. low-speed compressor.
c. propeller shaft.
d. cartridge turbine.

96. (656) The vertical scale EGT thermocouples produce a DC-millivolt signal that is

a. directly proportional to the sum of the exhaust gas temperature probe outputs.
b. inversely proportional to the sum of the exhaust gas temperature probe outputs.
c. inversely proportional to the average exhaust gas temperature.
d. directly proportional to the average exhaust gas temperature.

97. (657) The constant factor in the operation of the vertical scale fuel flow transmitter is the

a. fuel volume.
b. impeller rpm.
c. signal output.
d. fuel velocity.

98. (658) The EPR transducer used in the vertical scale engine instrument system uses a

a. tube-type amplifier and discriminator, and an inductive bridge circuit.
b. tube-type amplifier and discriminator, and a capacitive bridge circuit.
c. transistor-type amplifier and discriminator, and an inductive bridge circuit.
d. transistor-type amplifier and discriminator, and a capacitive bridge circuit.

99. (659) Which of the vertical scale engine instrument systems uses eight of the channels in the converter?

a. EPR.
b. RPM.
c. EGT.
d. Fuel flow.

100. (660) What type signal do the thermocuples supply to the EGT channel boards?

a. AC voltage.
b. DC voltage.
c. AC millivolt.
d. DC millivolt.

101. (661) The purpose of the fuel flow channel board is to

a. filter the tachometer generator signals.
b. amplify and discriminate the error signal.
c. phase shift the tachometer generator signals for correct indicator pointer deflection.
d. amplify and modulate the tachometer generator signals.

102. (662) What is used for protection of the channel boards?

a. A fuse for each board.
b. A fuse for all the boards.
c. A circuit breaker for each board.
d. A circuit breaker for all the boards.

103. (663) The vertical scale rpm indicators are calibrated to indicate

a. percent of rpm.
b. increments of 10.
c. percent of RPM X 10.
d. revolutions per minute.

104. (663) The RPM indicator labeled N1 shows the

a. average RPM of the engine's low- and high-speed compressors.
b. speed of the engine's high-speed compressor.
c. speed of the engine's low-speed compressor.
d. RPMs below 60 RPM.

105. (664) What is the main difference between the vertical scale EGT and RPM indicator?

a. Calibrated scale.
b. Method of illumination.
c. Number of movable tapes.
d. Method of reading the tapes.

106. (664) The vertical scale EGT indicators are calibrated in 10° increments in the upper half of the temperature range and in 50° increments in the lower half. The reason for this difference is that the

a. engine cruise speed is in the lower range.
b. sensors are not accurate in the upper range.
c. lower half of the range covers the critical temperatures.
d. upper half of the range covers the critical temperatures.

107. (665) The vertical scale fuel flow indicator is read in

a. gallons per hour X 100.
b. gallons per minute X 1000.
c. pounds per hour X 1000.
d. pounds per minute X 100.

108. (665) What cancels the servoloop operation in the vertical scale fuel flow indicator?

a. A rate generator.
b. A feedback potentiometer.
c. A control transformer.
d. A linear synchro.

109. (666) Identify the vertical scale engine instrument that has its own complete servoloops.

a. EPR.
b. EGT.
c. RPM.
d. Fuel flow.

110. (666) In which of the vertical scale systems is the signal sent directly from the signal-sensing unit to the indicator?

a. EPR.
b. EGT.
c. RPM.
d. Fuel flow.

111. (667) Which of the following conditions will cause the word "OFF" to appear on the tape of a vertical scale engine instrument?

a. Exceeding the capacity of the instrument.
b. Breakage of the tape drum spiral spring.
c. Stoppage of the gear train mechanism.
d. Failure of the 115-VAC power supply.

112. (668) In the vertical scale EGT system, the phasing of the signal which causes the motor to drive upscale or downscale is decided in the

a. chopper.
b. clipper.
c. power amplifier.
d. followup potentiometer.

113. (668) The DC millivolt signal from the thermocouples is applied to what section of the vertical scale EGT system?

a. The modulator circuit.
b. The dual chopper.
c. The cold junction compensator.
d. The feedback potentiometer.

114. (669) In the vertical scale fuel flow system, the signal induced into the stators of the XMTR TX is sent where?

a. To the rotors of the indicator CTs.
b. To the stators of the indicator CTs.
c. To the amplifier clipper.
d. To the power amplifier.

115. (670) Refer to figures 6-2, 6-4, 6-5, and 6-6 of the text. One of the primary differences between the EPR vertical scale engine instrument system and the other vertical scale engine instrument systems is that the EPR system

a. connects the transmitter to the indicator by a synchro system.
b. mechanically connects the servomotor to the synchro in the indicator unit.
c. only allows the indicator servomotor to drive when its control phase is energized.
d. requires a servoloop in the transmitter unit as well as one in the indicator unit.

116. (670) In the vertical scale EPR system, what type of device is used to sense the difference between engine inlet and exhaust pressure in the EPR transducer?

a. A bourdon tube.
b. An aneroid.
c. A dual bellows.
d. A single bellows.

117. (671) What is the first step in the operational check of the vertical scale instrument system?

a. Turn power on and insure the "OFF" flag disappears.
b. Visually check all components with power off.
c. Connect the EIS analyzer.
d. Run the engines.

118. (672) Relating to the vertical scale engine instrument system (EIS) analyzer, which of the following is correct?

a. It is restricted to bench work.
b. The power source is self-contained.
c. It regulates engine operation for the test purposes.
d. It simulates both converter input and output signals.

119. (673) On the converter test set, the VTVM unit measures the

a. indicator servomotor fixed-phase excitation voltage and control phase voltage.
b. indicator servomotor fixed-phase excitation voltage only.
c. indicator servomotor control phase voltage only.
d. followup potentiometer voltages only.

120. (674) In the rpm vertical scale system, if the feedback signal from the indicator to the converter modulator is lost, the servomotor will

a. drive off-scale low.
b. drive off-scale high.
c. remain stationary at last reading.
d. not drive off-scale, but will fluctuate.

121. (675) A low EGT indication on both vertical scale EGT indicators would most likely be caused by a defective

a. EGT probe.
b. converter unit channel board.
c. indicator.
d. balance potentiometer.

122. (676) If a high or low indication appeared on both vertical scale fuel flow indicators, the most probable cause would be a defective

a. transmitter.
b. indicator.
c. converter modulator.
d. engine.

123. (677) Suppose the EPR reading was low on the pilot's and engineer's vertical scale indicators, the most probable cause would be a

a. defective amplifier in the transducer servoloop.
b. defective amplifier in an indicator servoloop.
c. leaking exhaust pressure bellows.
d. low system supply voltage.

124. (678) The EIS analyzer can be used to bench check

a. all vertical scale engine instrument indicators.
b. most vertical scale engine instrument indicators.
c. all vertical scale engine instrument transmitters.
d. most vertical scale engine instrument transmitters.

END OF EXERCISE

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AVIONICS INSTRUMENT SYSTEMS SPECIALIST

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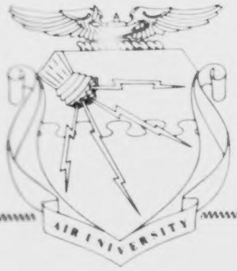
Volume 5

Liquid Quantity, Utility, and Recording Systems



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Preface

THIS FIFTH volume of the *Avionics Instrument Systems* course covers the systems with which you, as an avionics instrument systems specialist, will spend most of your time. The great variety of problems encountered in them and the variety of indications resulting from similar problems causes liquid quantity indicating systems to appear to be very difficult. For this reason, we devote all of Chapter 1 to these systems.

Chapter 2 deals with utility systems, which includes position indicating systems, accelerometers, and standby compasses. Chapter 3 covers systems used to record inflight data.

In each chapter, you will study the operation, inspection, operational checks, bench checks, removal and replacement of components, and troubleshooting of the systems covered.

Illustrations are provided to clarify the text. The code numbers appearing on them are for preparing agency identification only.

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This volume is valued at 24 hours (8 points).

The material in this volume is technically accurate, adequate, and current as of August 1981.

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NOTE: In this volume, the subject matter is developed by a series of student-centered objectives. Each of these carries a three-digit number and is in boldface type. Each sets a learning goal for you. The text that follows the objective gives you the information you need to reach that goal. The exercises following the information give you a check on your achievement. When you complete them, see whether your answers match those in the back of this volume. If your response to an exercise is incorrect, review the objective and its text.

Liquid Quantity Indicating Systems

WE START THIS volume by discussing the liquid quantity indicating systems. This chapter contains two sections, each covering instrument systems that measure the quantity of liquids. First, we will discuss the float-type system. It is similar to the fuel indicating system used on automobiles. This type of system was used extensively on early aircraft, primarily for fuel quantity indications. The float-type systems are also used in our modern aircraft for hydraulic fluid quantity and engine oil quantity indicating systems.

The second section is concerned with the capacitance-type liquid quantity indicating system. Today it is the most commonly used method of measuring liquid quantities on an aircraft.

1-1. Resistance-Type Liquid Level Indicating System

The basis of liquid measurements, such as the pint, the quart, the liter, and the gallon, is the amount of space or volume a liquid occupies. Suppose, for example, you wanted to measure out 1/2 gallon of water but you had only a gallon container. You would fill that container half full, as indicated by the *level* of the water in the container. The indicating systems you must maintain operate on this principle of measuring the level of a liquid in a container.

The resistance-type indicating system uses a float and mechanical linkage arrangement to detect changes in the level of fuel, oil, or hydraulic fluid in a tank or reservoir. This float assembly is part of the remote transmitter which is also called the tank unit. The tank unit is electrically connected to an indicator. The power required to operate this system is 24 to 28 volts DC. The voltage may vary slightly but this variation does not affect the operation of the system because the system is centered on a bridge circuit.

Now, let's examine the components and operation of a typical resistance-type liquid quantity indicating system.

800. Identify components of a resistance-type liquid level indicating system and state how the system operates.

Tank Unit. The tank unit senses changes in liquid level and transmits an electrical signal to the indicator in the cockpit. It mechanically measures the height of the liquid in the tank. Figure 1-1 is a cutaway view of a liquid level transmitter. This type of transmitter must be mounted outside the tank by the flange (G in fig. 1-1). It may be mounted on the top, bottom, or side of the tank.

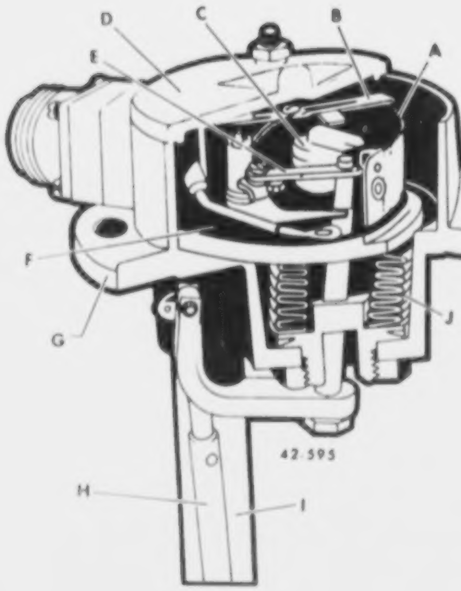
The float (not shown) is in direct contact with the liquid and is directly supported by the liquid. The liquid's rise or fall moves a linkage which is connected to the operating rod (H). This rod is located beside the fulcrum pipe (I) just under the electrical compartment or housing (G). An arm attached to the top of the rod is connected to a bellows (J). The bellows seals the electrical section off from fuel vapors. This seal prevents the possibility of fire which could occur if fuel vapors were to enter the electrical section.

Mechanical linkage connects the bellows to the linkage assembly (E) in the electrical section. This assembly transfers the movement directly to the contact arm (B) of the potentiometer assembly, which includes the resistance strip, the wiper arm, and the wiper arm linkage (F).

The wiper of the contact arm makes contact with the curved resistance strip (A) in the potentiometer assembly (F). In many of these transmitters the contact arm also closes a warning switch (C) which closes the circuit to a low-fuel warning light on the pilot's instrument panel. The internal parts of the transmitter are protected by a dust cover (D), which is secured by three screws.

Indicator. The indicators of a float-type system give 65°, 90°, or 120° of pointer movement, depending upon the design. The dial may be marked FULL and EMPTY, or may show gallons or pounds.

A study of the indicator mechanism diagram will give you a good understanding of how the mechanism works. The indicator is primarily a ratiometer type of movement. It has a moving magnet for the rotor (item M in fig. 1-2). The rotor is mounted inside a copper cylinder, which dampens rotor movement and prevents excessive needle pointer (P) oscillation. The pointer is attached directly to the rotor and moves with it. The ratiometer movement includes two stationary coils (C_1 and C_2), mounted 120° apart, which deflect the permanent magnet rotor. A third



A. Resistance strip
B. Contact arm
C. Warning switch
D. Dust cover
E. Linkage assembly
F. Potentiometer assembly
G. Electrical compartment or housing
H. Operating rod
I. Fulcrum pipe
J. Bellows

Figure 1-1. Cutaway view of a liquid level transmitter.

coil, known as the scale length coil (C_3), determines the range of needle (N) movement (N and S at C_1, C_2, and C_3 indicate polarity.)

Besides the ratiometer movement in the indicator, various other units contribute to the correct operation of the system. One is the bar magnet pull-off mechanism. It moves the pointer to an off-scale EMPTY indication when no electrical power is being applied to the system. Some indicators also have mechanical stops which limit pointer travel.

Operation. Study figure 1-2 as we study how the system operates. This system is one of the basic circuits in use. Your thorough understanding of it will help you understand many other types of systems that use bridge circuits. A principle to keep in mind is that the greatest portion of electric current will always take the path of lowest resistance. This does not mean that all of the current flowing through this circuit will follow the easiest path. A small amount of current always flows in a complete circuit that has a difference in potential applied to it.

Twenty-four volts are supplied to the basic circuit in figure 1-2. Therefore, a voltage potential is applied to the scale length coil, C_3; to the two deflection coils, C_1 and C_2; and to the resistance strip. Current-limiting resistors R_1 and R_2 control the magnetic field strength of coil C_3. Thus, R_2 will have one value for an indicator with a 65° scale range, a second value for a 90° range, and a third for 120° range.

The resistance strip makes up one leg of the bridge circuit. The two deflection coils form the other leg. The wiper arm, electrically connected to the two deflection coils, serves as the bridge and connects the two legs.

When there is equal potential on either side of the wiper, no current flows across the bridge, and the pointer should rest at midscale. For a more complete picture of how the system operates, let's trace the flow of current through the circuit. We will set the wiper at two different positions.

First, look at figure 1-3, in which the wiper is resting at the R− screw. (When the tank is full and the float is at its highest position, the wiper will rest at R−.) A voltage potential (24 volts) is applied to coil 3 and the resistance bridge circuit—coil 1, coil 2, and the resistance strip (A). Because of the position of the wiper arm, there is no voltage drop from ground to the wiper arm. This places the ground potential on the wiper. There is no appreciable current flow through coil 2. Because equal potential exists at coil 2, no magnetic field is created around this coil; therefore, there is no magnetic force from the coil to act upon the rotor. Through coil 1 and back to the source of power we must drop the entire 24 volts, so quite a lot of current flows in coil 1. The current flow through coil 1 creates a magnetic field around it and attracts the permanent magnet rotor. Since the strength of the field around the coil governs the amount of rotor movement, the pointer will be deflected the full distance of the scale.

Figure 1-4 shows the wiper resting at the R+ screw. When the tank is empty and the float is at its lowest position, the wiper will rest on R+. There is no current flow through coil 1, because potential is equal at both ends of the coil. With no current flow through coil 1, no magnetic field is created around this coil. Therefore, there is no magnetic force from coil 1 to act upon the rotor.

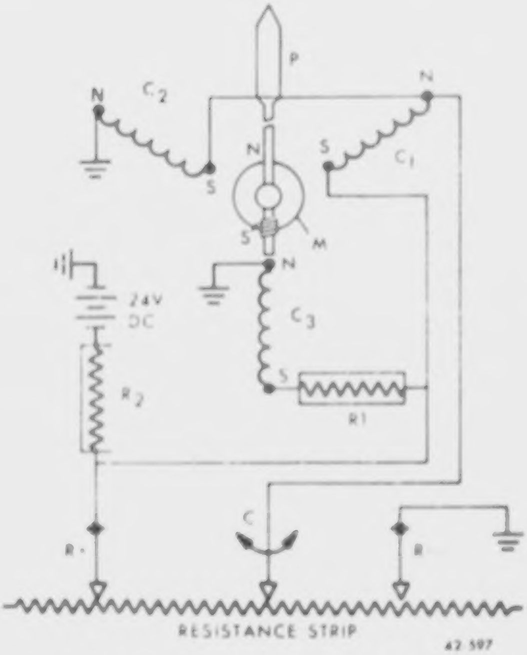


Figure 1-2. Schematic diagram of a two-wire liquid level system.

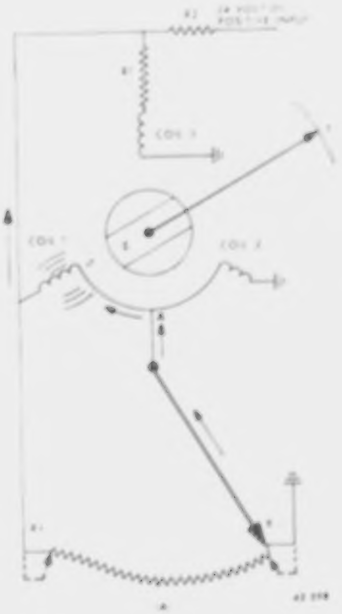


Figure 1-3. Schematic diagram of a two-wire liquid level system indicating a full tank.

Current flow approaches maximum in coil 2, because we must drop almost the entire 24 volts across it. The magnetic field created by current flowing through coil 2 attracts the permanent magnet rotor. Since the strength of the field around the coil governs the amount of rotor movement, the pointer will be deflected the full distance of the potentiometer.

When an aircraft is in flight, the level of fuel in the tanks will be continually dropping. The wiper will move steadily across the resistance strip from R− to R+. When the wiper crosses the midpoint of the resistance strip, the amount of current flow in coil 1 will steadily decrease in relation to current flow in coil 2, and the pointer will be moved toward the EMPTY mark on the dial. If the pointer does not indicate EMPTY when the tanks are empty, an adjustment at the R+ screw should correct the error.

The stronger the magnetic field is around the scale length coil, the less distance the pointer will be deflected. The amount of current flow through the scale length coil is constant, even though the amount of current flow in one indicator is different from the amount in another. This is the reason that one indicator will have only 90° of pointer movement and another will have 120°. Remember R2? It has a value for each degree of pointer movement.

Exercises (800):

1. What type of movement is used in the DC liquid level indicator?

2. What prevents fuel vapors from entering the electrical compartment of a tank unit?

3. What transfers float movement to the potentiometer assembly?

4. Explain the purpose of resistors R_1 and R_2 in figure 1-2.

5. What determines the range of pointer movement?

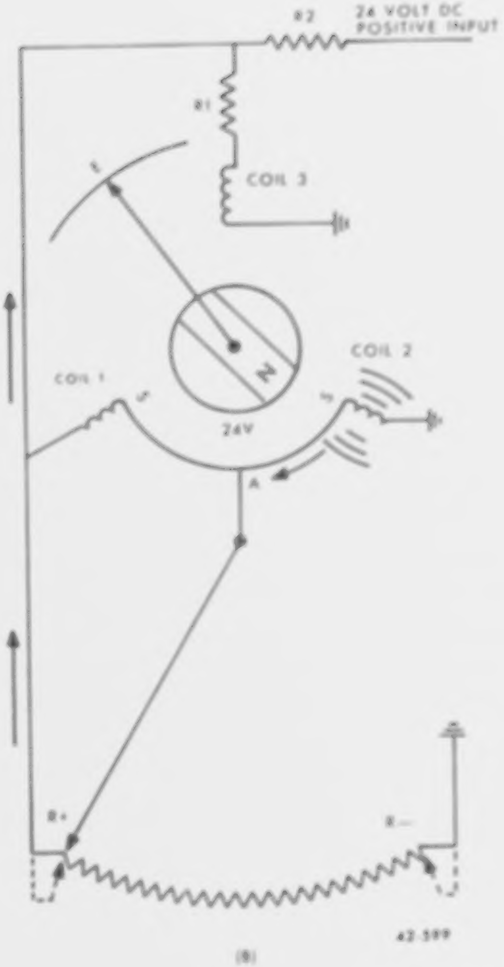


Figure 1-4. Schematic diagram of a two-wire liquid level system indicating an empty tank.

6. Describe the legs of the bridge circuit of the resistance-type liquid quantity indicator.

7. What should the pointer indicate when no current is flowing across the bridge in the indicator?

8. The amount of pointer movement in the indicator is governed by the strength of the magnetic field around which coils?

9. When the tank unit wiper arm is resting at the R+ end of the resistance strip, what is the current flow through coil 1?

10. When the fuel tank is empty, the tank unit wiper arm will rest at which end of the resistance strip?

11. When fuel is being used and the tank unit wiper passes midpoint, what is the effect on the current flow in coil 1 and coil 2?

12. What determines scale length of deflection?

891. Identify steps for maintaining and troubleshooting a liquid level indicating system.

Maintenance Requirements. In this discussion, we cover the test equipment used to calibrate and troubleshoot the liquid level indicating system. We also discuss inspection procedures and how to remove and install components.

Test equipment. The test equipment used on the float system is the 0–1 field tester. You can use the 0–1 tester to check on both single and dual indicators and the tank units of the various float systems. The tester is actually an indicator and tank unit inclosed in a single case and is equipped with all of the necessary leads and connections. The indicator is used to make the checks on individual tank units, and the transmitter is used to check the indicators. The applicable technical order lists the part number of the plastic dials and gives information regarding the indicators on which they will be used.

To make resistance checks on the tank unit or the indicator, you need an ohmmeter or a multimeter. The multimeter is also used to locate wiring troubles in the circuit or in individual components.

Calibrations. The electrical connector on the tank unit has two pins. One is connected to the wiper arm and the other to the R+ screw. The R+ screw is electrically connected to the positive end of the resistance strip. It is adjusted to correct the empty setting (see fig. 1-5). The R– screw is electrically connected to the other end of the resistance strip and is internally grounded to the case. The R– screw is adjusted to correct the full setting.

If the pointer moves past the FULL position mark on the indicator, adjust the R– screw to correct the error. If the screw is turned in the correct direction, the contact moves along the wiper, adding more resistance to the circuit. As this happens, the current flow decreases. This reduction, in turn, lessens the strength of the magnetic field around the deflection coil. As a result the permanent magnet rotor is not deflected enough to move the pointer past the full position mark. On the other hand, if the pointer does not read FULL when the tank is full, turn the screw in the opposite direction to correct the error. The R+ screw is similarly adjusted to correct for EMPTY indication errors.

Troubleshooting. Although troubleshooting the two-wire system is usually easy because of its simplicity, we shall point out some of the common troubles. If the system is inoperative because of system power failure, the indicator pointer will be off scale below EMPTY

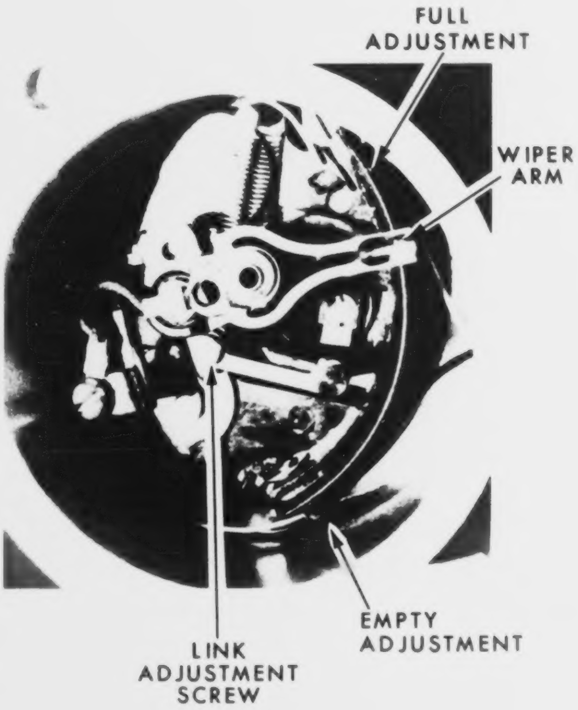


Figure 1-5. View into top of a liquid level transmitter.

because the bar magnet pull-off mechanism will pull the pointer off scale, below EMPTY, any time no power is being applied to the system. The permanent magnet rotor will not be affected by the deflection coils if the system is not energized.

When a no-power indication appears check for a blown fuse. If the fuse is satisfactory, a continuity check of the power and ground leads with a voltmeter will reveal an open if one exists. Check the terminals and leads; also replace any faulty unit.

Probably the most common trouble that occurs in the system is an open wiper contact caused by dust or corrosion that prevents contact of the wiper with the resistance strip. This causes the system to operate erratically. Other malfunctions can result in a midscale indication. For instance, an open wiper will not conduct current. In this condition there is equal voltage across both of the deflection coils, so a midscale indication results. A continuity check of the wiper lead to the indicator will reveal an open unless the open happens to be inside the transmitter. If the wiper lead shows continuity, remove the tank unit cover and check the continuity from the resistance strip through the wiper. Look for rust spots on the strip and for dirt or other foreign matter accumulated between the resistance strip and the wiper. Replace the strip if it has rust spots. Remove dirt with a clean, lint-free cloth. When you make this check, avoid damaging the ohmmeter by making certain that the system is not energized.

If the trouble is caused by a loss of wiper tension, reset the wiper according to the technical order directions for that particular tank unit. Too much tension causes excessive wear of the resistance strip; too little tension results in an open circuit. Sometimes the wiper will become shorted-to-ground, in which case you will see a FULL position indication because most of the current will be flowing through coil 1.

Removing components. The maintenance fundamentals we covered at the beginning of Volume 4 apply to this system. Before you remove a tank unit, make sure the tank is empty, especially if the transmitters are mounted on the bottom or side.

Installations. This type of transmitter must be installed with a gasket to prevent leaks. The case of the tank unit is the system ground; therefore, it must be bonded properly for the system to operate.

Inspection. Check that the indicator is mounted securely and that electrical connections are tight. Be sure that the cover glass is not scratched or broken and that the indicator is in good overall condition. Check the transmitter for leaks. Be sure it is mounted securely and properly safety wired. Check that the electrical connector is tight.

Bench check. Because the 0–1 tester can check many types of systems, we cannot cover all of them here. Instead, we cover one 90° indicator that is typical of all indicators. Remember to bench check a specific liquidometer component, you must know its part number. Refer to the applicable TO for specific bench check procedures.

Scale characteristic tests. To check the scale characteristics of an indicator, connect it electrically to the 0–1 tester. Hold the appropriate transparent test dial in place over the indicator glass. Then turn the transmitter knob of the tester from EMPTY through its intermediate positions to FULL. Note the indicator pointer position to determine whether it falls within the corresponding scale position of the test dial.

Tank unit scale error tests. Connect the tank unit to the 0–1 tester. Move the float arm to empty. The tester indicator should read "0" on the 0–90 scale. Move the float arm to full. The tester indicator should read 90 on the 0–90 scale.

If the readings are incorrect, equalize the error so that the total indicator travel will be either inside or outside both end markings by the same distance pivoting the contact arm (fig. 1-6) with your thumb or forefinger.

If the pointer travel does not indicate 0 to 90 after the contact arm is centered, loosen the link adjustment screw (fig. 1-5) very slightly and increase or decrease the length of contact travel. Slide the adjustment toward the base (to the left) of the contact arm to increase length of travel; slide the adjustment outward from the base to decrease travel length. Do not remove the link adjusting screw. Tighten it before you recheck the contact travel length.

Exercises (801):

1. Identify the test set used for testing the DC liquid level system components.

2. The liquid level tester is actually made up of what two components inclosed in a single case?

3. What happens when you turn the R+ or R– screws?

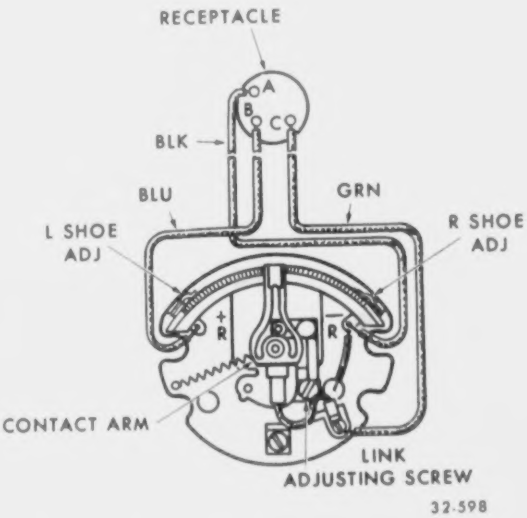


Figure 1-6. Potentiometer alignment and wiring diagram.

4. When calibrating the liquid level system, which screw is used for the FULL adjustment and which is used for the EMPTY adjustment?

5. Given a liquid level indicator system with a blown fuse, what will be the malfunction indication?

6. What is the usual cause of an open between the wiper arm and the resistance strip?

7. When you find a scale error in a tank unit, how do you equalize the wiper travel?

8. How do you make resistance checks on the DC liquid level system?

9. To correct an incorrect fuel reading, the tank unit ____________ ____________ or ____________ ____________ ____________ screw can be adjusted.

10. If the indicator reads below full when the tank was full, the adjustment screw would be turned in such a direction to ____________ resistance to the circuit and in turn ____________ the amount of current flow to increase the strength of the magnetic field around the deflector coil.

1-2. Capacitance-Type Fuel-Quantity Indicating Systems

Because the function of a capacitor is so important to the operation of this system, in this section we begin by reviewing a capacitor in use and then go on to discuss a basic capacitance bridge, a basic system, electrical adjustments, compensation, components, and then system application. Finally, we discuss maintenance requirements and test equipment.

802. State design and operating features of capacitors, and identify the main units of the capacitance fuel-quantity indicating system.

Capacitance. A capacitor (or condenser, as it is often called) is an electrical device in which electricity can be stored. It is composed of two plates of conductor material separated by an insulator (dielectric). A capacitor may be charged by a DC source such as a battery. As a result, electrons are removed from one plate and flow through the external circuit to the other plate. The charge built up results from a deficiency of electrons on one plate and an abundance of them on the other. After a period of time, the capacitor becomes fully charged; that is, the potential difference between the plates equals the voltage of the charging source (battery, in this case).

The capacitance or value of a capacitor is measured in terms of farads. However, the farad is such a large unit of measure that it is seldom used. Most capacitors used in industry have a capacitance of millionths of 1 farad, or microfarads (μf). Some units are even smaller and have capacitances that are measured in terms of micromicrofarads ($\mu\mu f$).

Capacitance depends upon three factors: (1) the surface area of the plates, (2) the distance between the plates, and (3) the material (or dielectric) between the plates. The larger the plate surface area in the capacitor, the greater the unit's capacitance. The closer the plates are to each other, the greater the capacitance. The dielectric material helps to determine the capacitance because all substances vary in the number of electrons that can be forced out of their normal positions by an external electric force. Therefore, some materials are much better dielectrics than are others.

As a matter of comparison, various materials are given a number (K factor), which compares them to the dielectric constant of a vacuum, which is 1. Various materials and their dielectric constant are air—1.000586, 115-145 octane fuel—1.971, and JP-4 fuel—2.083.

It follows, then, that if you change the dielectric material between the plates of a capacitor, you change the capacitance. The higher the K factor of the dielectric, the greater the capacitance possible.

When capacitors are connected in parallel, the total capacitance is the sum of the individual capacitances. When capacitors are connected in series, the total capacitance is equal to the reciprocal of the sum of the reciprocals of the individual capacitances in the series circuit.

When a capacitor is connected in a circuit to which an AC source is applied, the capacitor is charged first in one direction and then in the other. The current appears to flow through the capacitor, but does not, though the effect is the same as if current were passing through it. An AC ammeter placed in the circuit will show a steady deflection, just as if there were no capacitor. However, current flow lessens when a capacitor is placed in a circuit. This indicates that the capacitor does offer opposition to current flow. This opposition is called capacitive reactance, and it is measured and expressed in terms of ohms.

In AC circuits, resistors, inductors (coils), and capacitors have one thing in common. They all oppose the flow of current. They don't do this in the same way, however. When an AC voltage is applied to a circuit containing capacitance only, the capacitance opposes current flow in such a way that the current leads the voltage by approximately 90 electrical degrees. This occurs because the capacitance opposes any change in voltage. The higher the capacitance, the less the opposition or capacitive reactance. This effect is opposite to that produced when inductors or coils are placed in the circuit. An inductor in an AC circuit opposes the flow of current in such a way that the current lags the voltage by approximately 90 electrical degrees. You need a good knowledge of these principles and the forthcoming material to understand how the capacitance-type quantity indicating systems operate. The capacitance-type system is used to measure fuel, oil, or liquid oxygen quantity. Since these three systems operate similarly, we will discuss only the capacitance fuel quantity system.

System Components. The capacitance fuel-quantity indicating system accurately indicates the weight (mass) of usable fuel in the tanks of an aircraft. The main units of the system are an indicator, a tank unit, a bridge unit, and an amplifier. In most systems, the bridge unit and amplifier are a single unit, mounted in the same case. In later systems the bridge and a transistorized amplifier are built into the indicator. The complete unit is sealed in the indicator case.

The tank unit is mounted within a cell (section) of a fuel tank. It serves as a probe whose electrical capacitance depends, among other things, upon the level of the fuel in which it is immersed. By measuring this capacitance, you can determine how much fuel is in the tank. The capacitance of the tank unit is measured in the bridge unit. The voltage produced by the unbalanced bridge is fed to the amplifier, and then sent to drive a servomotor in the indicator. As the servomotor drives, it rebalances the bridge. In so doing, it moves the indicator pointer until it indicates the weight of fuel in the tank.

Exercises (802):

1. When a capacitor is fully charged, what does its potential difference equal?

2. What is the unit of measure of capacitance?

3. What three factors determine the capacitance of a capacitor?

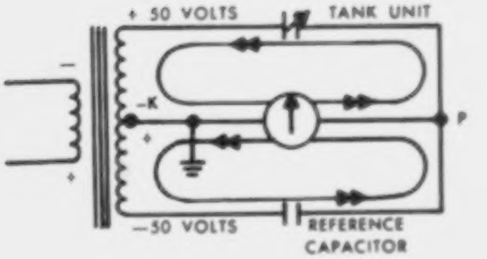


Figure 1-7. Balanced bridge.

4. What is the total capacitance of a number of capacitors connected in series?

5. What are the main units of a fuel quantity indicating system?

6. Which unit measures the capacitance of the tank unit?

803. State how the capacitance of a tank unit is measured and transferred to the indicator to reflect full level.

Basic Capacitance Bridge. To understand where and how the electrical signal is developed, let's take a closer look at the bridge. The tank unit mounted in the fuel tank is really a capacitor. Again, the capacitance of any capacitor is determined by (1) the area of the plates, (2) the distance between the plates, and (3) the material between the plates (dielectric).

The first two of the factors remain constant in a given capacitor, but the third factor is variable. Since fuel and air have different dielectric constants (JP-4 = 2.083 and Air = 1.000586), a tank unit's capacitance increases as the fuel level increases. Conversely, the less fuel there is in the tank, the lower the tank unit's capacitance.

The capacitance of the tank unit is measured by a capacitance bridge circuit. By comparing the capacitance of the tank unit to a known capacitance (reference), you can determine the tank unit capacitance at all times. A simple capacitance bridge circuit (fig. 1-7) consists of a tank unit and a reference capacitor. They are connected in series across a secondary winding of a transformer. A center tap from the secondary winding (at point K) is connected through a millivoltmeter (to point P) between the tank unit and the reference capacitor. The tank unit and the reference capacitor have equal values. In addition, the center tap divides the voltage of the secondary equally. Therefore, the induced voltage in either leg of the bridge will be in the direction shown by the arrows in figure 1-7. The line between the center tap and point P is common to both legs of the bridge. Thus the two voltages, which are equal in value but opposite in direction, will "buck" each other. Consequently, no current will flow along this line, and the bridge is balanced.

Now, let's unbalance the bridge by adding fuel. The capacitance of the tank unit increases. Therefore, the capacitive reactance decreases, allowing a greater current flow in that circuit. Because of the decreased opposition to current flow in the tank unit, a greater current flows through that leg than through the reference capacitor leg (see fig. 1-8). If there is a greater current through the tank unit than through the reference capacitor, the extra current must have passed through the common lead from K to P. (Current always flows from a lower potential to a higher potential.) With current flow from point K to

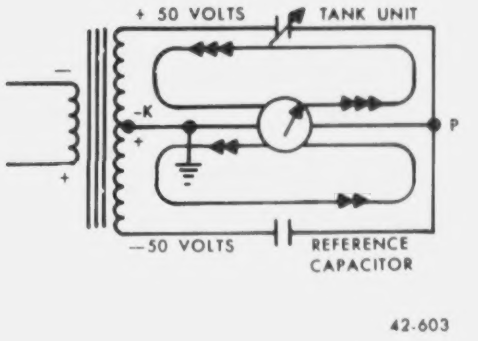


Figure 1-8. Unbalanced bridge (fuel being added).

point P, there must be a difference in potential between these two points. This difference is a signal IN PHASE only with the signal in the tank unit leg of the bridge.

Now let's unbalance the bridge by removing fuel. The capacitive reactance increases. As a result, the current flow in that circuit is decreased. Because of a greater resistance to current flow in the tank unit, less current flows through it than through the reference capacitor. If there is a greater current flow through the reference capacitor than through the tank unit, the extra current will go through the common lead from P to K. Current flow from P to K indicates that there is a potential difference between these two points. This potential difference is a signal that is in phase only with the voltage across the reference capacitor (see fig. 1-9).

We have demonstrated that any of three conditions can exist within a bridge circuit: (1) a balanced bridge, wherein the potential at K is equal to the potential at P (no signal); and (2) an unbalanced bridge, caused by adding fuel, with the potential at P higher than that at K, which causes a signal to be generated that is in phase with the tank unit; and (3) an unbalanced bridge, created by removing fuel, with the potential at K higher than that at P—that is, a voltage signal is generated that is in phase with the reference capacitor (out of phase with the tank unit).

Suppose we substitute an amplifier for the millivoltmeter between points P and K. For this substitution, we will use a two-stage amplifier that will amplify any signal resulting from an unbalanced bridge. With two stages of amplification, this amplifier's output has the same *phase relationship* as the input signal. This amplified signal energizes the variable-phase winding of a two-phase induction motor in the indicator. The fixed-phase winding of this motor is constantly energized from a tap on the power transformer primary. The voltage of the fixed-phase winding, however, is shifted approximately 90° by a fixed capacitor in the circuit. As a result, the indicator motor is *phase-sensitive*; that is, it will operate in either direction, depending upon whether the tank unit capacitance is increasing or decreasing.

Bridge Rebalancing System. We now need to find a way to rebalance the bridge. Otherwise, with the bridge out of balance, the indicator pointer moves continuously. It now becomes necessary to stop the pointer at the point on the dial that represents the weight of fuel remaining in the tank. This rebalancing action is produced by a potentiometer placed in the reference capacitor leg of the bridge.

The rebalancing potentiometer (pot) is connected across a portion of the transformer secondary. In addition, the wiper is connected in series with the reference capacitor. As the wiper moves from the lower end to the upper end of the pot, the voltage applied to the reference capacitor decreases. The voltage across the reference capacitor increases as the wiper is moved downward. This controls the voltage applied to the reference capacitor and therefore controls the potential at P.

In practice, the rebalancing pot is located in the indicator. The wiper of the pot is mechanically connected to the rotor shaft of the induction motor. The indicator motor drives the pot wiper (and indicator pointer) in the direction needed to maintain the same potential between K and P to balance the bridge. A simplified schematic of this arrangement is shown in figure 1-10.

Exercises (803):

1. What two factors of a tank unit remain constant?

2. How is tank unit capacitance determined with fuel in the tank?

3. What happens to the capacitive reactance of a tank unit when fuel is added to the tank?

4. When removing fuel from the tank, what is the phase relationship of the potential difference from P to K and the voltage across the reference capacitor?

5. What is the purpose of the amplified signal from the fuel-quantity amplifier?

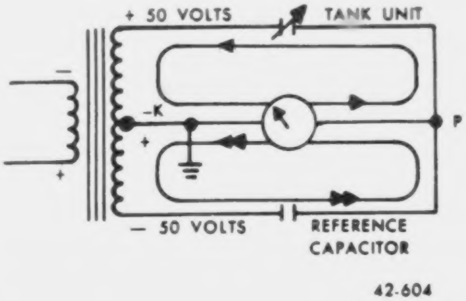


Figure 1-9. Unbalanced bridge (fuel being removed).

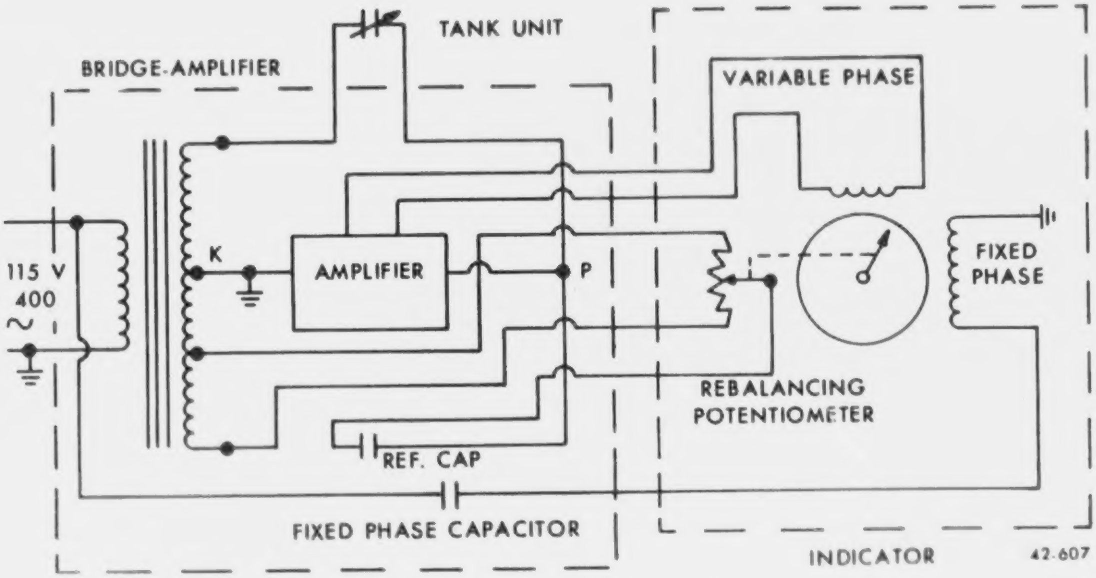


Figure 1-10. Basic system with rebalancing potentiometer.

6. How is the capacitance bridge of the fuel-quantity system rebalanced when fuel is added or removed?

804. Identify adjustment and compensation features of the capacitance fuel-quantity system.

Electrical Adjustment Circuits. Since capacitance fuel-quantity indicating systems are installed on several types of aircraft, they are designed with "built-in versatility." The basic system has been modified so that adjustments can be made to it.

The adjustment for the EMPTY position is provided by a pot across a portion of one end of the secondary winding. Adjusting the pot increases or decreases the current through the tank unit, indicating that a lesser or greater signal is being applied between K and P (see figs. 1-11). The FULL adjustment is provided by a pot placed across a portion of the other end of the secondary winding so that the potential across the reference capacitor and point P can be adjusted. The EMPTY and FULL adjustments provide the "fine" adjustments at either end of the scale range.

A coarse or range adjustment makes it possible to use only one type of bridge-amplifier unit on various aircraft systems or one type of bridge-amplifier section in an indicator. These circuits have several different taps on the tank unit end of the secondary winding (see fig. 1-11). By changing the range setting, you can vary the voltage applied to the tank unit. Thus you can increase or decrease the strength of the signal between points K and P. A limiting resistor is placed in series with the tank unit to protect the transformer secondary in case of a short circuit in the tank unit.

Compensation. As you have learned, liquids expand or contract with temperature changes. The capacitor fuel-quantity indicating system is practically unresponsive to such volumetric changes. The effect of increases in temperature on fuel is two-fold. It raises the level of the fuel between the electrodes of the tank unit but, at the same time, it reduces the dielectric constant of the fuel. These two effects serve to counterbalance each other. In addition, the capacitance per pound of fuel tends to remain nearly constant over the temperature range ordinarily encountered. This results in a more accurate indication of actual fuel quantity, because the energy available from the fuel depends upon mass (weight) rather than volume. However, *extreme* temperature changes will change the specific gravity (density); and variations will occur in the dielectric constants of fluids.

Another factor that affects the indication is fuel characteristics. Some fuel lots, or batches, have higher dielectric constants than others. This is especially true of modern jet fuels. In order to minimize the effects of these variations upon indicator accuracy, a special capacitor (compensator) is used. The compensator is always located at the lowest point in the fuel tank. In a system with one fuel tank, the compensator unit is located in the part of the fuel tank that is the last to drain. This unit remains completely immersed until the tanks are nearly empty.

In operation, the compensator is similar to a tank unit (though smaller), because it functions as a variable capacitor. Since it is kept completely immersed, its capacitance depends upon variations in fuel characteristics rather than upon fuel quantity. The compensator is electrically connected in parallel with the reference capacitor. It can also counteract deviations in tank unit capacitance caused by changes in fuel density characteristics.

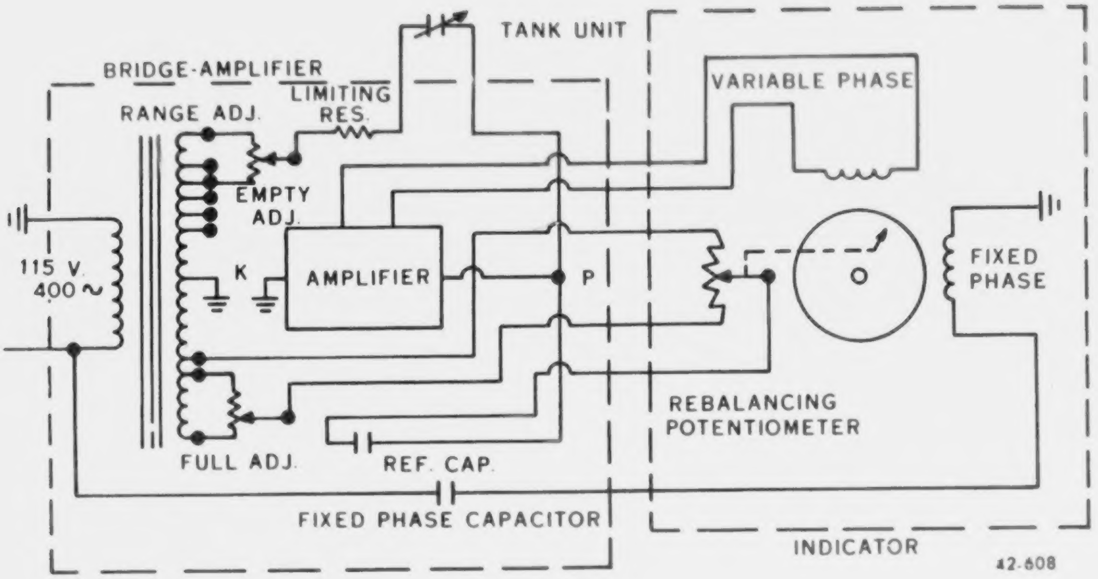


Figure 1-11. Electrical adjustments.

Compensators are available either as separate units or, from some manufacturers, as part of a tank unit. The separate units are mounted horizontally within the tank. Individual compensators come equipped with two electrical leads and connector plugs for quick installation. Tank units have either two or four leads. Compensators manufactured as an integral part of a tank unit usually consist of concentric electrodes with fixed plate areas and plate separations. They are mounted on the lower end of the tank unit. These compensated tank units have three electrical leads that use either terminal studs and lugs or connector plugs at the tank unit housing.

The number of compensators in a particular capacitance fuel-indicating system varies according to the type and model of the aircraft. Some aircraft, such as single-engine fighters, use only one compensator; multiengine aircraft may have a compensator in each tank.

Here's how the compensator works. Suppose you fill the tanks with fuel; and this fuel, because it is from a different lot, has a higher dielectric constant than the fuel formerly used. This difference, although it is very slight, increases the capacitance of the tank unit. Without compensation, the increased capacitance would unbalance the bridge; and the indication would be higher than normal. If the system has a compensator, the higher dielectric constant would also increase the compensator capacitance. This increased capacitance is electrically connected into the reference capacitor leg of the bridge, which raises the total capacitance of that leg by the same amount as the tank unit's capacitance was raised. You can see the counteracting effect that this can have. The result is that there is no indication error because of changes in fuel characteristics. The compensator works in a similar manner for changes in fuel density.

Exercises (804):

1. How is the capacitance fuel-quantity indicating system designed to be useful for more than one aircraft?

2. Why is the capacitance fuel-quantity indicating system not responsive to an increase or decrease in temperature?

3. How are changes in fuel characteristics and density counteracted in the capacitance fuel-quantity system?

4. Where is the compensator located in the capacitance fuel-quantity system?

5. How many connectors would a tank unit have that has a compensator built into it?

805. Define operational features of a capacitance fuel-quantity tank unit.

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Capacitance-Type System Components. Capacitance fuel-quantity indicating system components are manufactured by several companies. The units they produce vary in shape and size, though their functions are basically the same. Each aircraft type is equipped with a specific system. There have been several improvements in component design usually resulting in more accurate and lighter systems as well as in more simplified construction. As system components are improved they are installed on aircraft with specific inclusive serial numbers. For this reason, you must check the part numbers of the components against those specified by the applicable technical order when you need replacement units.

Tank Units. Tank units, sometimes called fuel probes, are manufactured in many sizes and shapes but as we have stated, they are basically nothing more than variable capacitors. They are variable because their capacitance depends upon the height of the fuel (dielectric) between their plates. Depending upon the physical shape of the tank in which they are to be installed, all tank units are one of two types: (1) noncharacterized or (2) characterized.

Noncharacterized tank units. These tank units have uniform plate areas throughout their length. They are designed for fuel tanks with uniform or regular horizontal cross-sectional areas, such as square or rectangular tanks. The capacitance of the tank unit varies uniformly as the tank is filled or emptied, and the tank unit output is said to be linear.

Characterized tank units. Characterized tank units do not have this uniform plate area throughout their full length. The units are designed for fuel tanks with nonuniform or irregular cross-sectional areas. Most modern aircraft fuel tanks are very irregular in shape. Characterizing the tank unit, then, is a way of tailoring a tank unit to a given tank so that you get a uniform capacitance throughout the full length of the tank unit. Then you use an evenly graduated indicator dial, regardless of the shape of the fuel tank. Tank units are characterized by their physical makeup in various ways. For example, they are characterized by a series of holes in the plates or electrodes. The holes must be of such size and in such location that the plate area is altered the proper amount along its length. Another method of characterizing tank units is to use two metallic patterns sprayed on a plastic tube. One pattern is grounded; the other, the active pattern, forms the second plate of the tank unit. By controlling the area of these two patterns, you obtain a linear output from the tank unit, regardless of the shape of the tank.

There are two general tank unit designs, flange-mounted and internally mounted. Flange-mounted units were designed for top or bottom mounting in a vertical position. Unlike the flange-mounted unit, the internally mounted tank unit is mounted completely within the fuel tank. There is a special mounting bracket for this type of tank unit, and the electrical connections are brought into the tank by bulkhead feed-through connector fittings.

Most tank units are cylindrical capacitors consisting of two concentric tubes. The inside tube forms the inner electrode (capacitor plate). The outside tube is the outer electrode. The open ends of the electrodes allow the fuel to flow between the electrodes, providing a dielectric that varies according to the fuel level.

In practice, you usually find more than one tank unit installed in a single fuel tank. In this way, fluctuations in fuel-quantity indication resulting from changes in the flight attitude of the aircraft can be minimized. When two or more tank units are installed in a single fuel tank, they are electrically connected in parallel. When the aircraft attitude changes, an increase in the fuel level in one tank unit is balanced by a corresponding decrease in capacitance in the other tank unit.

Exercises (805):

1. Define a basic tank unit.

2. What type of tank unit has a uniform plate area throughout its entire length?

3. Describe a characterized tank unit.

4. What are the two general designs of tank units?

5. How can in-flight fluctuations be minimized on a fuel-quantity indicator?

806. State the purpose of capacitance fuel-quantity simulators, and how they operate.

Simulators. A simulator with a fixed capacitor whose value is equal to the capacitance of an empty tank can be used in systems for either simulating the empty capacitance of a tank that has been removed or jettisoned or for selective indicating.

Simulators for removable or jettisonable tanks (drop tanks). Tank units are sometimes installed in some removable or jettisonable tanks. When the tank is empty, its tank unit still has a measurable capacitance. If the tank were to be removed or jettisoned, the loss of the empty capacitance would cause the indicator to read low. A simulated capacitance is connected into the system to compensate for this.

When the tank is removed, a switch is actuated by a release mechanism. This action energizes a relay that opens the drop tank's tank unit circuit and "switches in" the simulated capacitance.

The simulator, containing a 28-vlt DC relay and one or more variable and fixed capacitors, is housed in a hermetically sealed case. Such simulators can be used for one or more drop tank probes.

Since the simulated capacitance unit is hermetically sealed, maintenance is limited to removal and replacement. The variable capacitors are set at the factory.

Selective Indicating System. Many fighter-type aircraft have a single indicator and multiple fuel cells. The fuel probes are connected in parallel in these tanks. A fighter aircraft may have what is called a master feed tank. As fuel is pumped from this tank to the engine, it is replaced from the other tanks, such as wing, fuselage, and drop-tanks. To check the remaining fuel in the master feed tank, you could install a separate fuel-quantity system; but this would be a waste of both money and time, especially when the same information can be obtained with a single indicator system. All it takes is a simulator and a switch.

When the feed switch on the instrument panel is set to FEED TANK CHECK, the simulator relay is energized. The rest of the system fuel probes are grounded. The master feed tank probes go into the simulator through the energized relay contacts, through the simulator capacitors, and out of the connector plug to the indicator. The indicator shows the amount of fuel remaining in the master feed tank.

Exercises (806):

1. State two ways a simulator can be used in a fuel-quantity system.

2. State the capacitance of the simulator for a drop tank.

3. List the components of the simulator.

4. When a simulator is being used, what is the potential of the inactive fuel probes?

807. Cite the functions of the capacitive bridge circuit and state how the system operates.

Bridge Amplifiers. Regardless of the manufacturer, most bridge amplifiers are similar in design and identical in function. As we have stated, some manufacturers build the amplifier and bridge units together in one compact unit. Others are built as two separate units. Some of the newer types of bridge amplifiers are transistorized and are contained within the indicator case. Regardless of design differences, each has a bridge unit in which a voltage signal is developed; and each has an amplifier, which amplifies this signal and controls the phasing of the amplified signal. The amplifier is not a part of the measuring circuit. Therefore, the accuracy of the system is independent of vacuum-tube characteristics in the systems that contain tubes. The tubes in unsealed units can be replaced without affecting system adjustment. Since the system is continuously balancing, it operates at the null point and is entirely independent of normal frequency and voltage variations in the power supply.

Study a typical schematic diagram of a bridge amplifier (see fig. 1-12), will help you understand how the unit works. In this circuit, there is a two-stage vacuum-tube amplifier, a vacuum-tube discriminator, a power and bridge transformer, a bridge reference capacitor, and a calibrating potentiometer. A tank unit capacitor and an indicator induction motor are included in the circuit for explanation purposes only. These units are not a part of the bridge amplifier unit. Notice the similarity of this bridge circuit to the basic bridge circuit, shown previously in figure 1-7.

Let's now see how the phase of the signal voltage across the middle leg of the bridge—that is, across R—determines the phase of the current from the discriminator, under each of the following conditions.

Using fuel. When fuel is being used, I_B is larger than I_S. Thus, I_B determines the phase of the voltage across R (see fig. 1-12). Therefore, during the first half-cycle, the input

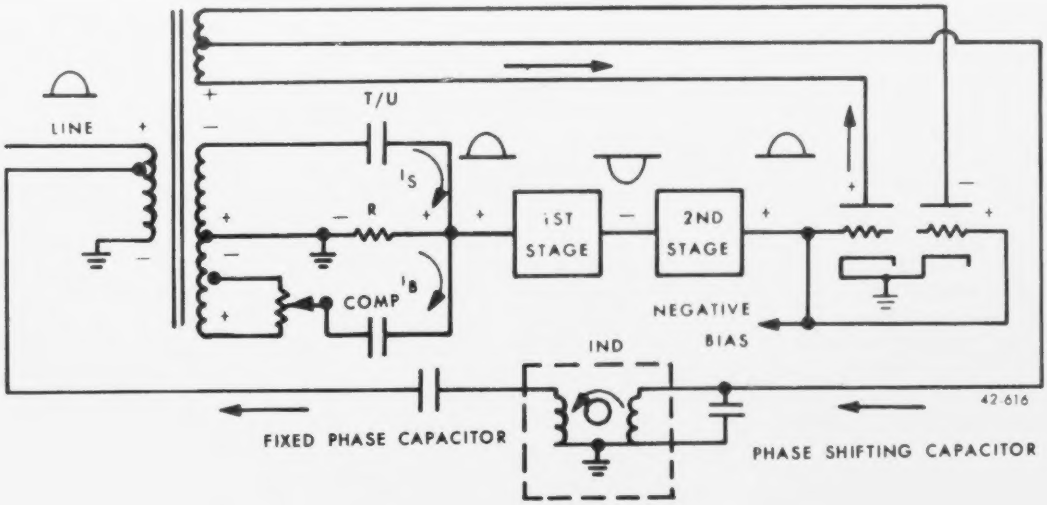


Figure 1-12. Fuel being used.

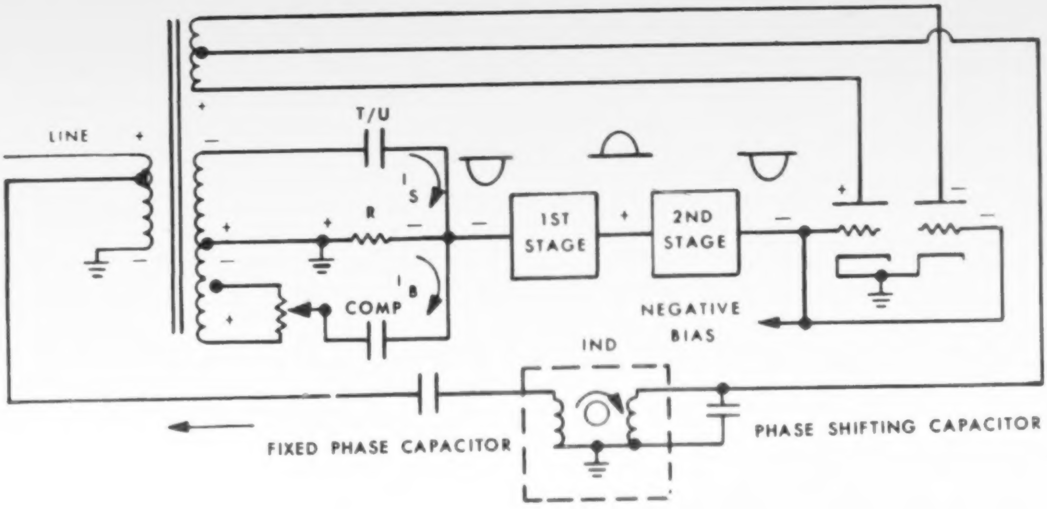


Figure 1-13. Fuel being added.

to the first state is positive. The first stage of the amplifier shifts the signal voltage 180°. The second stage of the amplifier also shifts the signal voltage 180°. The total shift in phase, then is 360°, and the signal to the discriminator grids is positive.

With these first half-cycle polarities, the left plate of the discriminator is positive; the right plate is negative. Therefore, the left half of the discriminator conducts. This current travels from the cathode of the left plate to the secondary center tap. It then goes through the variable-phase winding of the indicator motor to ground, and then back to the cathode. The left half of the discriminator conducts until the polarities reverse.

During the last half-cycle, I_B is still larger than I_S, and the phase of the signal voltage across R is determined by I_B. Thus, the input to the first stage is negative. The amplifiers shift the signal by 360°, and the signal to the discriminator grids is negative. This prevents tube conduction, even though the right plate of the discriminator is now positive. As long as fuel is being used, this sequence, discriminator conduction only on the first half-cycle continues.

Adding fuel. When fuel is being added, I_S is larger than I_B. I_S determines the phase of the input signal (see fig. 1-13). Thus, the input to the amplifier is negative. With the 360° phase shift through the two stages of amplification, the signal to the grids of the discriminator is negative. With negative grids, there can be no conduction through the discriminator tube.

During the last half-cycle, I_S is still larger than I_B. The input to the amplifiers is positive. With the last half-cycle polarities, the right plate of the discriminator is positive. Therefore, the right half of the discriminator conducts. This current also travels through the variable-phase winding of the indicator motor to ground. The right half of the discriminator conducts until the polarities reverse. As long as fuel is being added, this sequence, discriminator conduction on the last half-cycle, continues.

Balanced bridge. With a balanced bridge, no signal is being fed to the discriminator grids. Since these grids are biased negatively, there is negligible tube conduction. With a negligible current through the amplifier-phase winding of the indicator induction motor, its rotor will not turn.

Compare the phasing of the current from the discriminator to that of the line phase. You can see that the discriminator current is in phase with the line phase when fuel is being used. You can also see that it is 180° out of phase with the line-phase current when fuel is being added. These phase conditions enable the indicator to rotate both ways. The output current from the discriminator is pulsating DC.

Component Functions. A typical bridge-amplifier diagram is shown in figure 1-14. All of the adjustments and connectors are accessible from the front end of the unit. Study this diagram closely as we explain the function of the various parts of the circuit.

The bridge signal originates between points P and K. A loading impedance consists of a 0.0068-μf capacitor in parallel with a 0.01-μf capacitor and a 10M-ohm resistor.

The left-hand triode section of V2201 is the first-stage amplifier, and the right-hand triode section of V2201 is the second-stage amplifier. The DC positive plate voltage for the amplifier is developed by a selenium rectifier and filter network consisting of 0.01 and 0.047-μf capacitors together with a 390K-ohm resistor. The output of the first stage is developed across the 130K-ohm resistor. The output of the second stage is developed across the 150K-ohm resistor. These two resistors are called plate-load resistors. The input to the second stage is developed across the 10M-ohm resistor. The coupling capacitor between the first and second stages and between the second stage and the discriminator are the two 0.01-μf capacitors across terminals 4 and 5, and terminals 2 and 3 respectively of E2201.

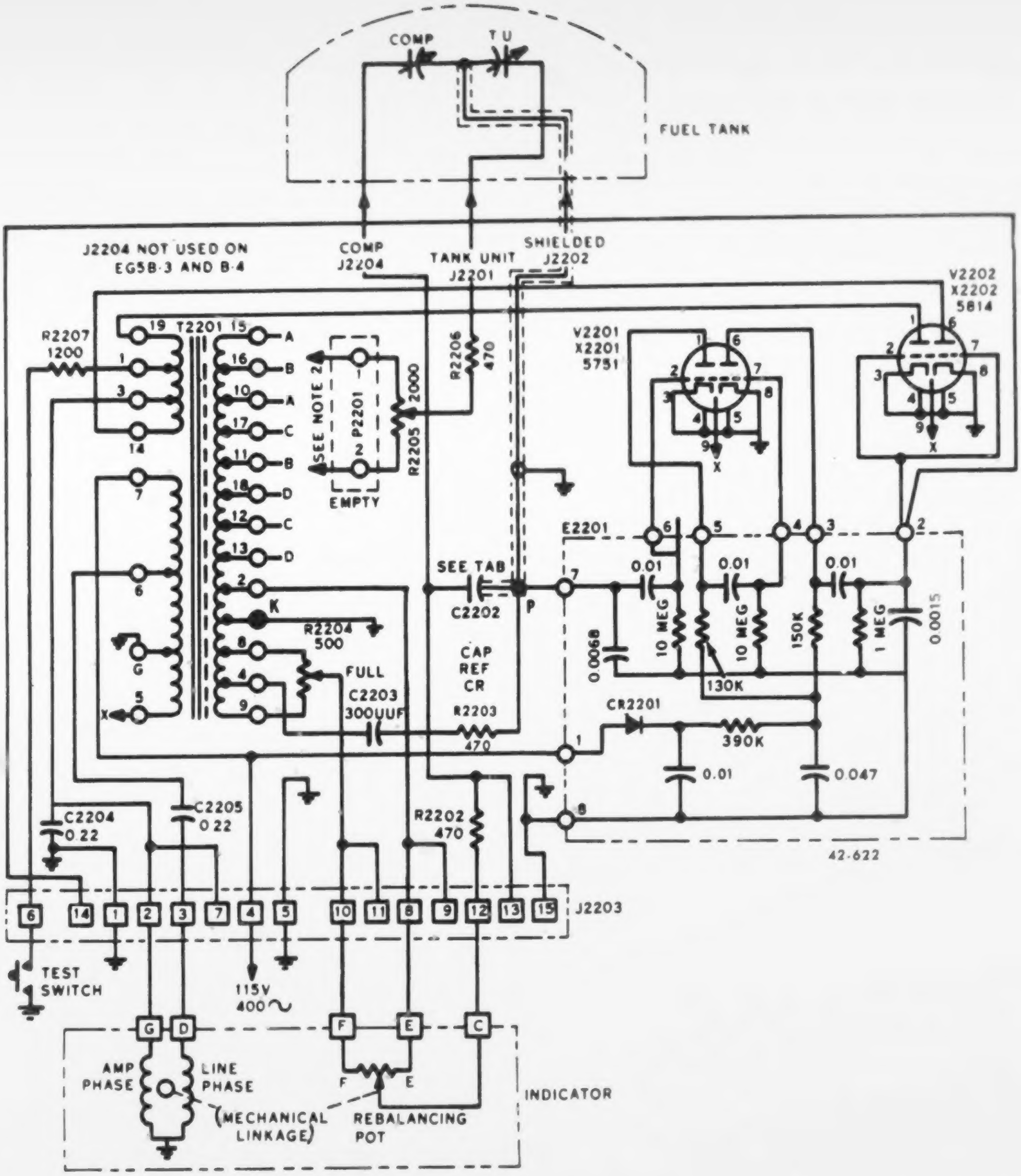

COMP
T U
FUEL TANK
J2204 NOT USED ON
EG5B-3 AND B-4
COMP
J2204
TANK UNIT
J2201
SHIELDED
J2202
V2202
X2202
5814
V2201
X2201
5751
R2207
1200
T2201
R2206
470
SEE NOTE 2
P2201
R2205
2000
EMPTY
E2201
SEE TAB
C2202
P
K
R2204
500
FULL
C2203
300UUF
CAP
REF
CR
R2203
470
0.01
0.01
0.01
0.0068
10 MEG
10 MEG
150K
1 MEG
0.0015
130K
CR2201
390K
0.01
0.047
R2202
470
C2204
0.22
C2205
0.22
42-622
J2203
TEST
SWITCH
115V
400~
AMP
PHASE
LINE
PHASE
(MECHANICAL
LINKAGE)
REBALANCING
POT
INDICATOR

Figure 1-14. Typical bridge amplifier schematic.

The discriminator tube is V2202, a twin triode with its grids connected. The negative bias (grid bias) controls discriminator tube conduction. This grid bias is developed by the 0.0015-μf capacitor and the 1M-ohm resistor. All resistors and capacitors mentioned so far are located in the resistor-capacitor can, E2201.

R2202, R2203, and R2206 are all 470-ohm current-limiting resistors that protect the transformer from short circuits in the three front connectors, or leads. The two 0.22-μf capacitors are the phase-shifting capacitors for the two-phase induction motor. The transformer supplies power to the bridge, to the plates of the discriminator, to the amplifier-phase winding of the motor, and to all of the tube filaments.

The sensing voltage is adjusted by positioning P2201 and the wiper on the empty adjustment, R2205. The voltage across the balance potentiometer is adjusted by positioning the wiper on the 500-ohm full adjustment. Note that two reference capacitors, C2202 and C2203, are connected in parallel and act as one capacitor. The No. 1 tap on the primary of T2201 is connected to a remote test switch. This switch is used for a quick operational check.

The test switch unbalances the bridge circuit whenever a check of the system is desired. When the test switch is closed, voltage is reduced on the tank unit side of the bridge, greatly unbalancing the bridge circuit. As a result of this unbalance, the indicator drives toward the empty end of the dial. If the system is operating normally, releasing the test switch will restore the bridge balance and return the indicator pointer to its original position. The test switch is usually located on or near the indicator.

Other types of bridge amplifiers vary in circuit design. Some use a vacuum tube as the source of DC plate potential instead of the selenium rectifier. Some units obtain full-wave rectification from the twin triodes of a discriminator tube. In this way, one tube serves two functions. Some units have, instead of one transformer, separate power transformers and bridge transformers. Some bridge amplifiers are mounted on a shock-mounted rack, while others are not.

Exercises (807):

1. Why is the capacitance fuel-quantity system entirely independent of normal frequency and voltage variations in the power supply?
2. Where does the voltge signal originate in a fuel-quantity capacitance bridge circuit?
3. Referring to figure 1-12, what determines the phase of the voltage across R when fuel is being used from the tank?
4. When adding fuel to the tank, what does the discriminator do during the last half-cycle of conduction?
5. What is the phase relationship of the discriminator current to line current in the bridge when fuel is being used?
6. In the bridge amplifier, what develops the DC positive plate voltage?
7. What is the purpose of the current-limiting resistors in the bridge amplifiers?
8. Electrically, what happens when the test switch is used to test the fuel-quantity system?

808. Identify components of the fuel-quantity indicator in terms of their function and operation.

Indicator. The indicator is normally calibrated in terms of pounds of fuel available. Basically, this unit consists of a two-phase AC induction-type motor, a gear train, a rebalancing potentiometer, a dial, and a pointer.

The motor assembly contains two coil assemblies, a rotor assembly, and a gearbox assembly. The indicator pointer and the pot wiper are moved by the action of the motor-gear train combination. The pointer and wiper are connected to the output shaft. Therefore, both move in the same direction and through the same angular motion. Thus, as the motor repositions the pointer, it repositions the balance pot wiper also. At the same time, it varies the voltage applied to the reference capacitor and rebalances the bridge. The direction of rotation is such that the pot acts to reduce the bridge output until a balance is obtained. (Other types of indicators are available which provide such additional parts as a low-level switch, a high-level switch, a transmitting pot, and any combinatin of these components.) The various components of the indicator are housed in a hermetically sealed anodized-aluminum case.

Let's now see how the two-phase induction motor of the indicator operates when fuel is being used or added (see fig. 1-15 and 1-16).

The output of the discriminator is fed to the variable-phase winding of the motor. At the same time, the fixed-phase winding is continuously energized by the fixed line-phase current. The discriminator current will be either in phase or 180° out of phase with the line current. To obtain a rotating magnetic field, we must cause the discriminator current to lead or lag the fixed-phase current through the fixed-phase winding by approximately 90°. This is brought about as follows:

The capacitor in series with the fixed-phase winding produces with the inductance of the winding, a circuit that is nearly series-resonant. In a series-resonant circuit, the current is in phase with the voltage across the entire branch. Therefore, the current through the fixed-phase

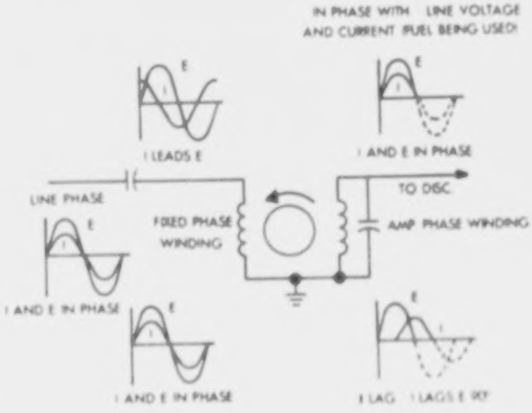


Figure 1-15. Phase relationships in the indicator motor when fuel is being used.

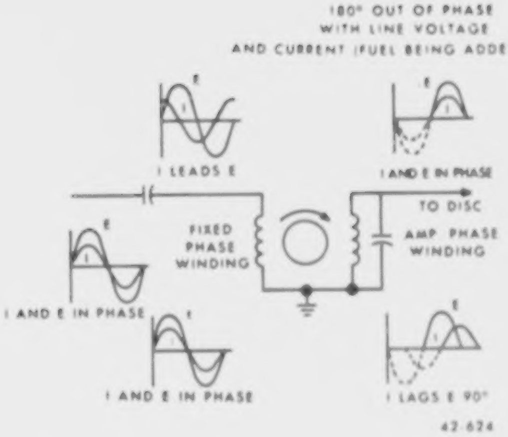


Figure 1-16. Phase relationship in the indicator motor when fuel is being added.

winding is in phase with the line voltage. The capacitor, in parallel with the variable-phase winding, produces a circuit that is nearly parallel-resonant. In a parallel-resonant circuit, the voltage across the parallel branch is in phase with the current to the parallel circuit.

However, the current in the inductive branch, the motor winding, lags the voltage across the parallel circuit by 90°. Therefore, the current through the variable-phase-winding lags the discriminator current by approximately 90°. The current through the motor winding is out of phase by 90°, and the motor rotates to turn the pointer and indicate the new level of fuel.

Exercises (808):

1. Identify the signal-sensing device in the indicator.

2. What does the capacitor in series with the fixed-phase winding produce?

809. State why coaxial cable is used in the capacitive fuel quantity system and identify the type of connectors used.

Cabling. The electrical cables used between units of the fuel-quantity indicating system are of two types: (1) shielded or coaxial (coax) and (2) unshielded, or 400-Hz, leads.

A coax cable efficiently transfers electrical signals with a minimum of loss, interference, or radiation. Coax cables are used between tank units and bridge amplifiers. These consist of an inner conductor, a dielectric, an outer conductor or shield, and the outer jacket. The inner conductor provides a low-resistance path for electric current flow. The dielectric (a thick plastic tube) provides a fixed spacing between the inner and outer conductors and insulates the two conductors from each other. The outer conductor can be used as a low-resistance return path for the electrical circuit. However, in most installations, it is used as a shield and is grounded to the structure of the aircraft. The outer jacket is a tough, nonabsorbing insulator that is impervious to most acids, alkalis, and oils.

The fixed spacing maintained by the dielectric, the composition of the dielectric material, the size of the two conductors, and—in some cases—the length of the cable are all critical factors that determine the effectiveness of the coax cable in performing the function for which it was designed. A very small variation in any of these factors will alter the electrical properties of the coax cable and reduce its effectiveness. It should always be regarded as an instrument rather than as just another piece of wire.

Connectors. The various connectors used in the capacitance fuel-quantity indicating systems are special conductor disconnects. They are quickly and positively engaged or disengaged by means of a quarter-turn bayonet-locking mechanism. The connectors are impervious to extreme temperatures. They also resist vibration, moisture, pressure differentials, and foreign elements that may reduce operational efficiency.

Exercises (809):

1. Why are coaxial cables used in the capacitance fuel-quantity indicating system?

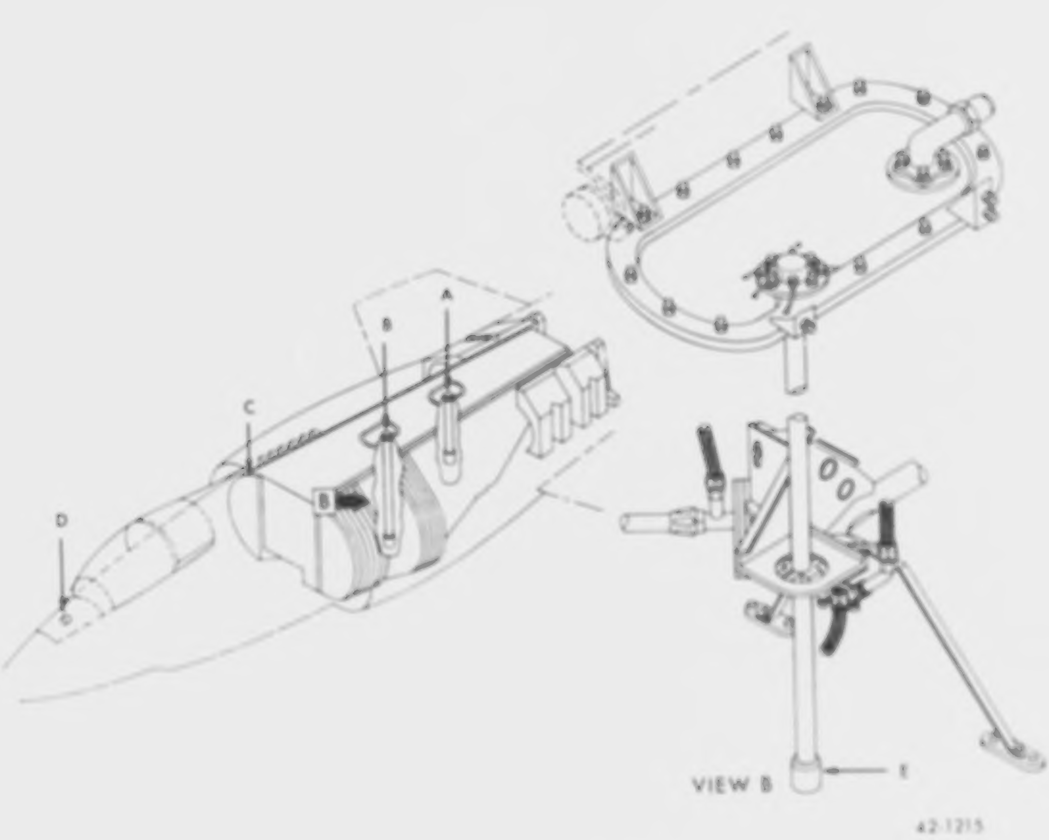
2. What type of connectors is used in the fuel-quantity indicating system?

810. Cite applications of capacitance-type fuel-quantity indicating systems.

Application of Capacitance-Type Systems. Up to this point, you have learned how the basic capacitance bridge develops an electrical signal. You have also learned how that signal is amplified and phased to give a reading on the indicator. We will not describe how these basic systems are used in fighter and cargo aircraft fuel-quantity indicating systems.

The fighter aircraft system. The fighter aircraft system (illustrated in fig. 1-17) consists of two transmitters (A and B), an amplifier-indicator (D), and the necessary wiring. One transmitter installed in the forward main fuel cell (C) and has a compensator (E) at the lower end of the tank unit. The other transmitter is in the aft center cell. Fuel drains from this cell last, during flight. Thus the compensator is covered with fuel at all times. The amplifier-indicator (D) is located on the right side of the upper instrument panel.

As stated earlier, the indicator is a hermetically sealed combination unit. It amplifies any unbalanced signal



A. Transmitter
B. Transmitter
C. Forward main fuel cell

D. Amplifier-indicator
E. Compensator

Figure 1-17. Tank unit installation.

from the system bridge circuit and provides a dial indication of measured fuel quantity, expressed in pounds. The indicator also contains a self-balancing capacitance bridge circuit, a three-stage transistorized amplifier; a reversible two-phase induction motor; and a gear train, pointer, case, cover glass, and dial. A schematic diagram of the indicator is presented in figure 1-18. Notice that the bridge circuit, together with the EMPTY and FULL adjustment pots, rebalancing pot, and points of signal pickoff (P and K), are very similar to that of the basic bridge, which was discussed earlier in this chapter. The transistorized amplifier is to the right of point P in figure 1-18. Notice the three transistors and their similarity to a triode tube. Comparing them to the triode tube, you may think of the base element (C) as the grid, the emitter element (B) as the cathode, and the collector (A) as the plate.

The first transistor at the left (see fig. 1-18) is the first stage of voltage amplification. The voltage signal from the bridge is applied to the base element. The amplified signal is then applied, through a coupling capacitor, to the base element of the second transistor. Here again, the voltage signal is amplified and applied to the primary of a coupling transformer. The secondary of this transformer applies the amplified signal to the base element of the third transistor. The transformer and the third transistor, together with the various resistors and capacitors, make up the power amplification stage.

Phasing. The current output of the power stage either leads or lags the current to the fixed phase of the two-phase induction motor. This lead or lag is approximately 90 electrical degrees whenever the bridge is unbalanced. Followup action takes place through the mechanical linkage. The linkage connects the rotor of the induction motor (B1) and the rebalancing pot (R14). Thus, the bridge is continouously unbalancing and balancing as fuel is being removed or added. The indicator requires two electrical inputs: (1) 28 volts (applied to pin M) for the transistorized amplifier and (2) 115 volts, 400-Hz (applied to pin H) for the bridge circuit and line (fixed) phase of the induction motor. Notice in figure 1-18 that the AC and DC power supplies have a common ground. This prevents damage to the transistors. The polarity of the power supply must not be reversed. All connections to the indicator are made through one connector on the back of the instrument. The FULL and EMPTY adjustments are

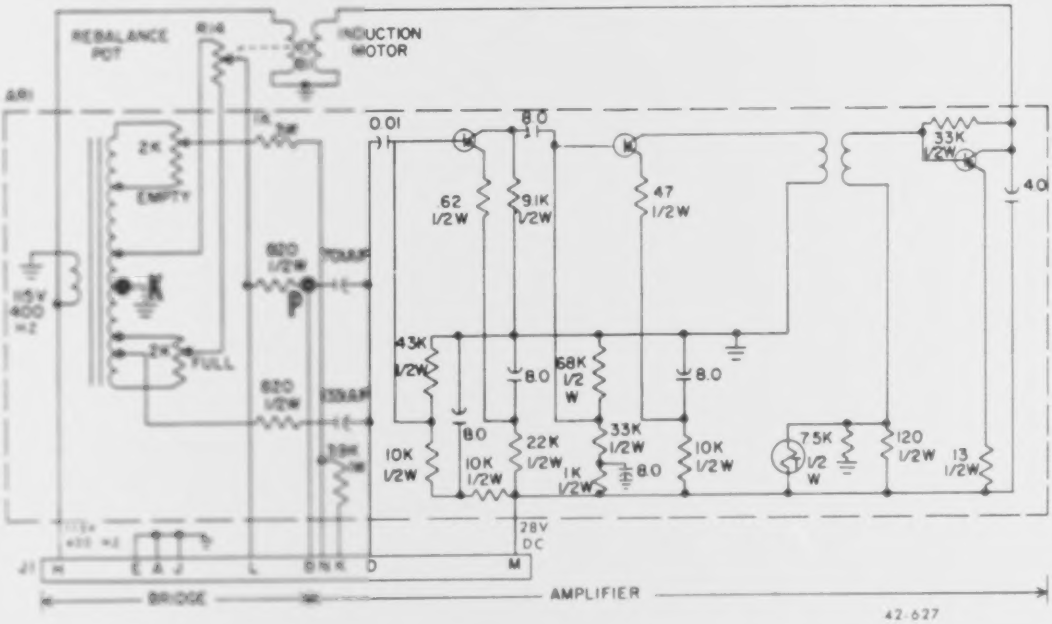


Figure 1-18. Schematic diagram of a transistorized indicator.

made with two screws located under the cover plate on the back of the instrument.

The cargo aircraft system. Cargo aircraft may have as many as ten separate fuel tanks, and each tank has a separate fuel-quantity indicating system. Cargo systems are very similar to the fighter system, since they contain one or more tank units and a transistorized indicator. Some tanks contain as many as five tank units.

Each tank unit lead is permanently attached to the tank unit and is fitted with an electrical bulkhead connector on the opposite end of the lead. There is one compensated tank unit in each tank.

The indicator contains a transistorized bridge amplifier. This bridge is almost identical to the one used in fighter aircraft (see fig. 1-18). The only differences are in the scale range and in the sizes of the resistors and capacitors in the bridge and amplifier circuits. The adjustment screws for the FULL and EMPTY positions are on the back of some of the indicators and on the bridge units of others.

The cargo aircraft fuel-quantity indicating system is provided with a means of totaling the fuel quantity of all tanks. One indicator shows this total at all times by means of a summation unit.

The signal summation unit (totalizer) is a device consisting of three hermetically sealed ratio units. It also contains an AN connector mounted on a chassis. Each ratio unit contains three or more voltage dividers (pots) and their related resistors. The RG 14E-3 unit, for example, has 10 voltage-divider (pot) legs all connected in parallel. The common signal out of the unit is connected to a pin of the connector. Each leg is tailored to an individual fuel tank by adjustment of a pot. When a small signal voltage is applied to each leg, the signals are added, since all legs are connected in parallel.

The total fuel-quantity indicator is like the individual tank indicators, except that it contains a null-balancing resistance bridge circuit instead of the capacitance bridge circuit. The resistance bridge compares a signal voltage from the signal summation unit with a reference voltage. Any unbalance of the bridge is amplified by a transistorized amplifier, the output of which energizes the variable-phase winding of the total fuel-quantity gage motor. The total fuel-quantity gage indicates the total fuel in pounds, and this represents the sum of the individual tank gage readings. All individual tank gages and the total fuel-quantity gage are mounted on the fuel control panel in the cabin of the cargo aircraft.

Let us now review what we have covered thus far. Refer to figure 1-19 to help you to understand the overall operation. Figure 1-19 is a schematic diagram of the No. 1 main fuel-quantity indicating system, including its power sources, tank units, indicator, and test switch. Also, the figure shows how the No. 1 main gage is connected to the signal summation unit and consequently to the total fuel-quantity gage. Visualize all other individual tank gages as they would appear connected to the signal summation unit. Notice the multiple switch that is used to check system operation. When this switch is pushed, the bridges in all individual tank gages are unbalanced so that the pointers rotate counterclockwise. Releasing the switch should cause the pointers to return to their original positions. You can use the totalizer push-to-test switch to check the totalizer circuit separately.

Exercises (810):

1. In a fighter-type aircraft with only one compensator, in which tank would the compensator be installed?

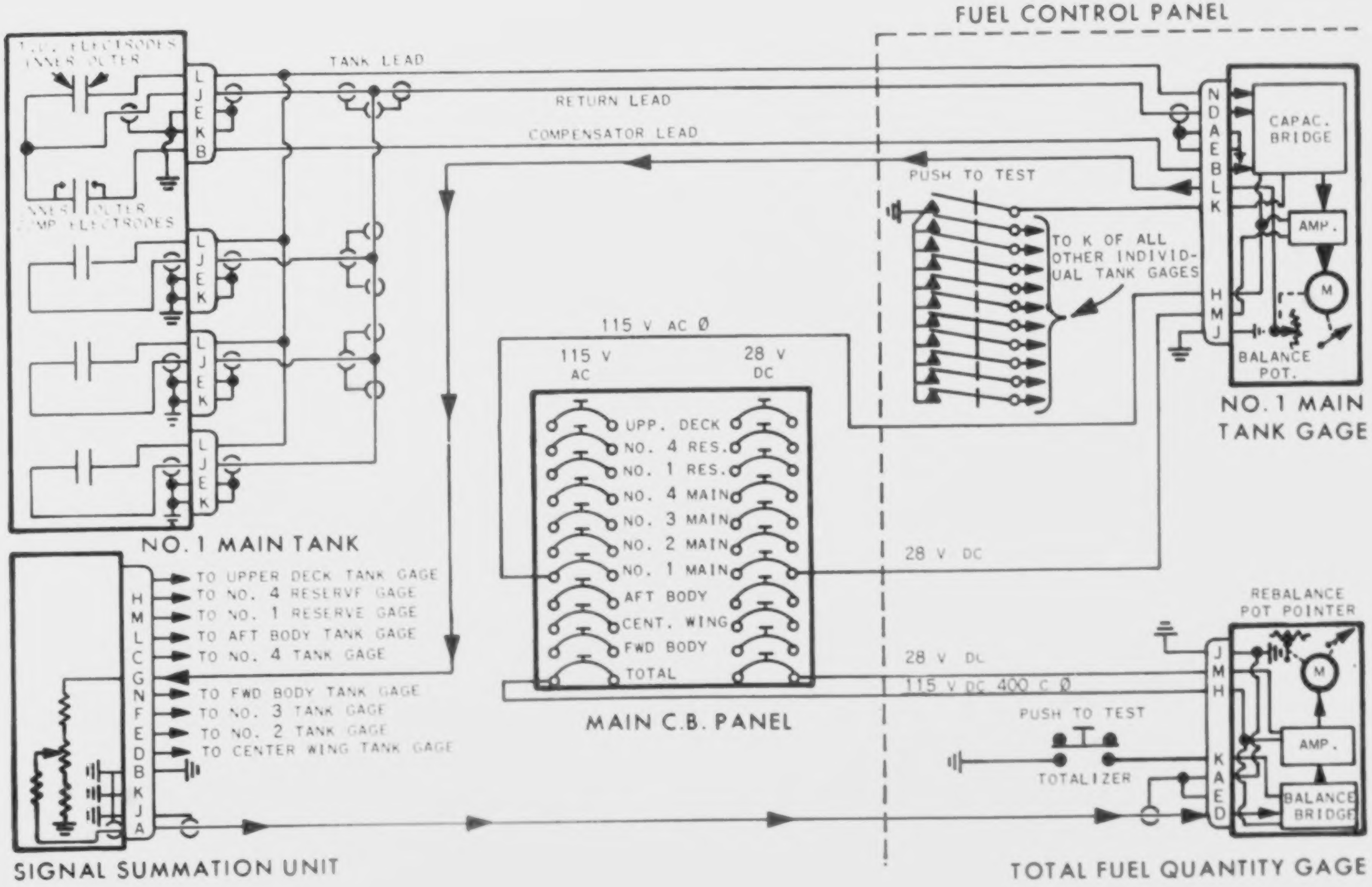

FUEL CONTROL PANEL
T.U. ELECTRODES
INNER OUTER
INNER OUTER
COMP ELECTRODES
L J E K B
L J E K
L J E K
L J E K
TANK LEAD
RETURN LEAD
COMPENSATOR LEAD
NO. 1 MAIN TANK
PUSH TO TEST
TO K OF ALL OTHER INDIVIDUAL TANK GAGES
N D A E B L K
H M J
CAPAC. BRIDGE
AMP.
M
BALANCE POT.
NO. 1 MAIN TANK GAGE
115 V AC Ø
115 V AC
28 V DC
UPP. DECK
NO. 4 RES.
NO. 1 RES.
NO. 4 MAIN
NO. 3 MAIN
NO. 2 MAIN
NO. 1 MAIN
AFT BODY
CENT. WING
FWD BODY
TOTAL
MAIN C.B. PANEL
28 V DC
28 V DC
115 V DC 400 C Ø
H M L C G N F E D B K J A
TO UPPER DECK TANK GAGE
TO NO. 4 RESERVF GAGE
TO NO. 1 RESERVE GAGE
TO AFT BODY TANK GAGE
TO NO. 4 TANK GAGE
TO FWD BODY TANK GAGE
TO NO. 3 TANK GAGE
TO NO. 2 TANK GAGE
TO CENTER WING TANK GAGE
SIGNAL SUMMATION UNIT
REBALANCE POT POINTER
J M H
M
AMP.
K A E D
BALANCE BRIDGE
PUSH TO TEST
TOTALIZER
TOTAL FUEL QUANTITY GAGE
42 631

Figure 1-19. No. 1 main tank fuel system schematic diagram.

2. When you are calibrating the transistorized hermetically sealed amplifier-indicator combination, where do you make the FULL and EMPTY adjustments?

3. On a cargo aircraft with multiple tank units in a tank, how many compensators would be required in each tank containing more than three tank units?

4. What is the difference between the cargo and fighter-type transistorized fuel-quantity indicators?

5. How are the voltage dividers connected together in a fuel-quantity signal summation unit for cargo aircraft?

811. Identify test equipment and procedures used to check capacitance fuel-quantity system operation.

Maintenance Requirements for Capacitance-Type Systems. Do you remember what we said about the importance of maintenance of the resistance-type system? Those comments certainly apply here. Because the capacitance-type system is more complex than the resistance type, we will first describe the operational check and test equipment. We will also discuss bench tests, calibration, inspection, and troubleshooting.

Operational check. A quick check of the operation of the system can be made with the push-to-test switch. First, connect external power to the aircraft; then, after system warmup, record the readings of all gages, including the totalizer. The totalizer should indicate the sum of the individual gages within 1.0 percent of the full scale of the dial. Next, hold the push-to-test gage switch closed and observe the counterclockwise rotation of all individual tank and total fuel-quantity gage pointers. If the totalizer circuit has a separate test switch, you must depress it to check the totalizer circuit. Allow the individual tank gage pointers to turn counterclockwise for at least 15 to 20 angular degrees. The totalizer pointer will not travel as far as the individual tank gage pointers. When you release the switch, the pointers should return to their original positions. If any pointer does not move or if it does not return to its original position, there is a defect in the system.

Test Equipment. The testers used with this type of equipment, although manufactured by several different manufacturers, all operate on the same principle. The different models or types vary in their range and physical makeup. However, the use and the care of all testers are similar.

MD-1 tester. The MD-1 tester consists of two variable capacitance units mounted in a metal case. It also has special cables and tee adapters to connect the tester into the aircraft fuel-quantity indicating system. The main variable capacitor in the tester has a direct calibrated range of 50 to 110 Pf. Higher capacitances, up to a maximum of 6100 Pf direct reading, can be obtained by adding in the proper step of a range-expanding capacitor. There are five steps of successive multiples of 1000 Pf each. The second variable capacitor, used for compensators, has a direct calibrated range of 10 to 210 Pf.

In a card holder inside the lid of the tester case, you will find an individual calibration chart for the variable capacitors of the tester. The calibration chart is arranged so that you add or subtract a correction factor from the dial reading in order to get a desired output. For example, you wish to simulate 150 Pf. You find the closest range on the correction chart and the correction (.12) is listed in the Add column. This means that you must add .12 to the dial reading of 149.88 to actually get 150.00. So you can see that a correction listed in the Add column means that you must subtract that correction from your desired value to determine your dial setting. Though the capacitors are adjusted closely, they can be measured with greater precision with the calibration correction. Connect the tester to the system through the connectors in the upper right corner of the tester. The 50- to 1,100-Pf section and the 10- to 210-Pf section are used for calibration and test purposes separately. You must leave the unshielded cable disconnected from the respective unused section of the tester. If you do not, a slight error will be introduced by the capacitance between the unshielded cables.

Variable-capacitance testers must be handled carefully, for they are precision instruments. Inspection and maintenance is limited to such things as lead wire and connector repair or replacement; replacing the desiccator; and cleaning the terminal pins, clips, and tee connectors. Instrument specialists should not attempt to calibrate these testers. They are laboratory-calibrated, and tampering will disturb the calibration, rendering the unit useless.

MD-2A tester. The MD-2A tester is used to measure capacitance and insulation resistance in tank units and cables while they are installed in the aircraft or in the shop.

The capacitance range selector knob selects measurement ranges of 0–100 pf (X1), 0–1000 Pf (X10), and 0–500 Pf (X50). The megohmmeter section of the MD-2A tester measures resistances from 0.5 megohm to 10,000 megohms in four ranges: 0.5 to 20 megohms, 5 to 100 megohms, 50 to 1,000 megohms, and 500 to 10,000 megohms. These values represent a very high resistance. The megohmmeter can be damaged if the test leads are shorted or used to measure resistance values below the range of the instrument. Keep the megohmmeter range selector in the CAL position except when you are actually checking insulation resistance. Do not check shorted tank units on a range higher than X1. Remember that you are working with explosive fuels. The insulation resistance checks can be very dangerous. Use ONLY authorized equipment to perform them and follow all precautions given in the TO. Using a multimeter or insulation breakdown tester could produce arcing in the tank that would ignite fuel vapors and cause an explosion. TO 1-1-688 lists equipment that is restricted from use on the aircraft. Capacitance resistance testers must be earth grounded during use. For aircraft use, the aircraft and tester both must be grounded to earth as well as to each other.

GTF-6 tester. Modern technology is constantly making great strides in providing more reliable and safer equipment in all areas of aviation and electronics. Although the MD-1 and MD-2A testers are still basic equipment used in the maintenance of fuel quantity systems, with technological advances these two testers have been combined into one case. You studied this type of test set in the 3-level course at Chanute. The test set includes three basic types of circuitry: (1) a capacitance circuit to provide direct-reading values of capacitance from zero to 5000 $\mu\mu$F in four ranges, (2) a megohmmeter circuit to provide direct-reading values of insulation resistance from zero to 10,000M ohms, also in four ranges, and (3) capacitance simulator circuits to simulate the capacitance-type fuel tank probes. The capacitance indicator is an analog meter which looks like the one used in the MD-2A. The tester functions the same as the MD-1 and MD-2A testers we have covered.

The application of digital concepts resulted in our newest piece of test equipment for capacitance type liquid quantity indicating systems. Whereas the earlier TF-20 series testers were bulky and weighed 35 pounds, the GTF-6 is smaller and weighs 25 pounds. It is easier to carry to and from the flight line.

As with the TF-20, capacitance measurement or capacitance simulation is selected by the capacitance function switch. The GTF-6 contains an analog-to-digital converter to display the capacitance or resistance values on a direct-reading in-line numeric type digital display. The GTF-6 also contains a self-test feature. Depressing the display test switch causes the digital display to read 8.8.8.8.8. Failure of this test indicates defective digits in the display. The other functions are basically the same as those of the other testers you have studied; however, the value to be measured must be within the range you have selected before you can get a readout. Blinking numbers indicate an overrange condition.

Tank unit capacitance is displayed in picofarads. If the display is blinking 199.95, the aircraft tank unit being measured had a capacitance greater than 200 Pf. Rotate the capacitance range switch one position at a time until you get a nonblinking readout. The first position reached, going up the scale, that yields a nonblinking reading will give the capacitance with the most accuracy. The same thing is true when measuring insulation resistance.

Exercises (811):

1. Explain an operational check of the capacitance fuel-quantity indicating system.

2. Identify the tester you should use for calibrating the capacitance fuel-quantity indicating system.

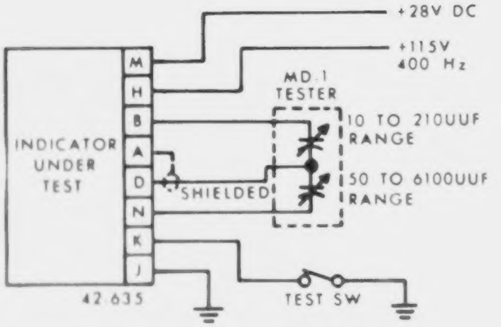


Figure 1-20. Indicator test circuit.

3. State what you can do to more precisely calibrate a capacitance fuel-quantity system.

4. What maintenance can you perform on the MD-1 capacitance tester?

5. For what is the MD-2A tester used?

6. Describe precautions you must observe when using the megohmmeter on the MD-2A tester. Why?

812. State procedures for bench checking capacitance fuel-quantity indicating system components.

Bench Checks. Every indicator and tank unit of questionable serviceability should be bench tested before it is sent to a depot. Also, all serviceable instruments should be bench checked before they are installed in an aircraft. Test the indicators by attaching them to a tester and the proper power source, as shown in figure 1-20.

To bench check a transistorized-type indicator, connect the indicator into a test circuit, as shown in figure 1-21. A 165-10, a 165-10-1000, or a 100x-2245 connector (Amphenol) is used for a mating connector. A switch is placed in each power lead. The 28-volt and the 115-volt power source must have a common ground. The polarities shown in figure 1-20 must be observed; that is, positive 28 volts DC to pin M, 115 volts AC to the H pin, and J pin to the common ground. This polarity prevents damage to the amplifier components.

Conduct the following described tests at an ambient temperature of approximately 25° Celsius (77° F.) Be sure the calibration of your test equipment is current before you use it.

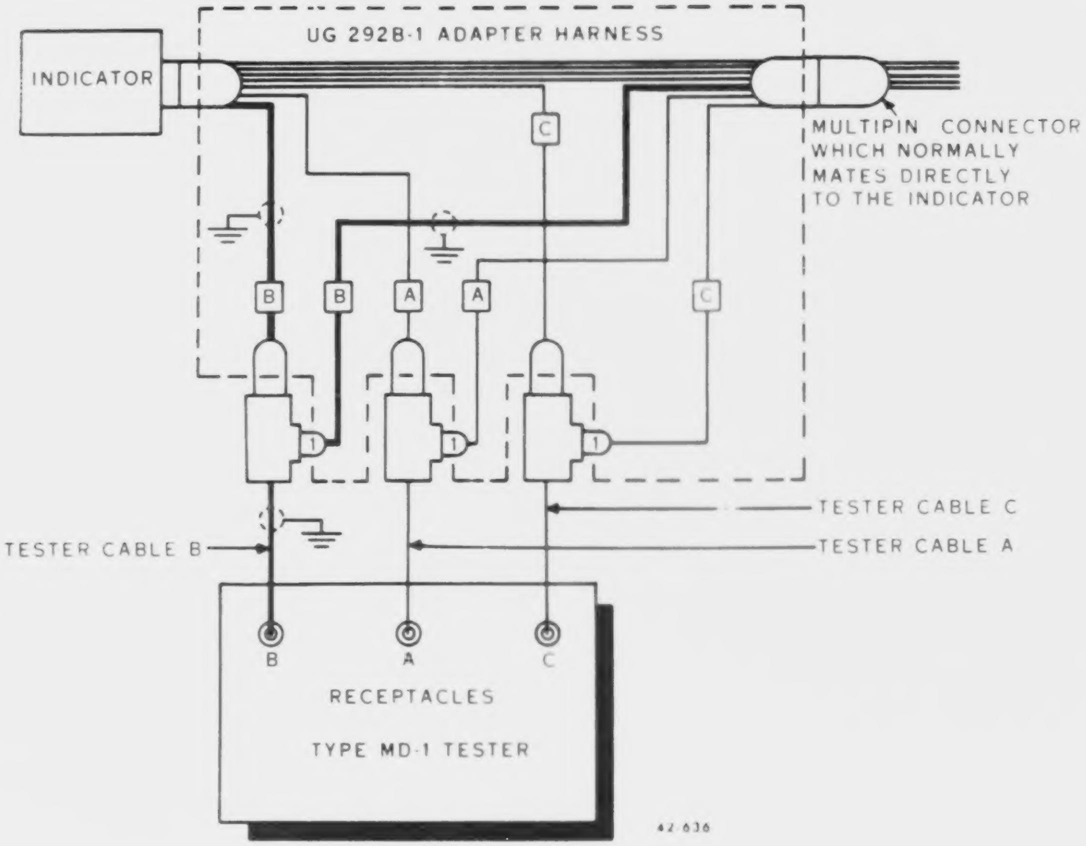


Figure 1-21. Preferred method of adjustment.

Test-switch check. The test-switch check determines the indicator response to test-switch operations. The check is performed in the same way as the preflight power-on check.

Adjustment check. The adjustment check determines whether the indicator empty and full adjustments are properly set. To perform the test on the transistorized indicator, refer to the applicable TO. Set and lock the 10- to 210-Pf range on the tester at the compensator capacity value of 62.5 Pf. Next, adjust the tester (50- to 60, 100-Pf range) to the nominal empty capacitance of 149.2 ± 0.5 Pf. Vary the setting by the tolerance listed for the empty capacitance value. If the center of the zero graduation mark is between the two extremes of pointer movement, the empty adjustment is correct. Then check the full adjustment by adjusting the tester (50- to 6, 100-Pf range) to the nominal full capacity value. Vary the tester setting ± 0.5 Pf as before. The center of the last graduation mark on the full side of the scale must be between the two extremes of pointer movement. If the indicator fails either the empty or full adjustment check, it may need only readjustment.

Linearity check. This is actually a scale-error check. It is useful in determining whether the indicator is correct throughout its full range. The capacitance between each main-dial graduation of the transistorized indicator is 15.47 ± 1.2 Pf. Determine the capacitance value of each main-dial graduation. For example, the nominal capacitance for the zero graduation is 149.2 Pf. The nominal capacitance value of the 500-pound graduation on the indicator would be 149.2 Pf plus 15.47 Pf, or 164.67 Pf. Compute the capacitance setting for the 1,000, 1,500-pound (etc.), settings in a similar manner. The MD-1 tester cannot be set accurately for two decimal places; however, you must use two decimal places in each case to prevent an error buildup in your calculations.

To check linearity, set the MD-1 tester to the nominal capacitance value for each of the instrument's main graduations. At each of these settings, vary the tester setting by plus 1.2 Pf and then minus 1.2 Pf. The linearity of the instrument is satisfactory if the center of each main-dial graduation lies between the two extremes of instrument pointer movement. The instrument must not hunt or oscillate at any dial graduation.

Zero signal check. This check determines whether the capacitance bridge is electrically balanced when the instrument pointer is at rest. You are actually measuring the signal voltage between points K and P when the capacitance bridge is balanced. Connect an electronic multimeter between indicator pins D and A (see fig. 1-20). Use a shielded meter lead, connecting the shielding to pin A and the meter ground terminal. Adjust the tester to position the fuel-quantity indicator pointer at zero. With the indicator at balance, the measured zero signal must not exceed 15 millivolts. Disregard any momentary voltage surges.

Dead-spot check. The dead-spot check determines the lag between rotor movement and capacitance change. When the indicator is approximately at midscale and at balance, note the MD-1 tester setting. Hold the indicator against your ear, and listen for rotor movement while slowly decreasing the capacitance of the tester. Stop adjusting the tester at the instant you detect rotor movement. Note the new tester setting, and determine the capacitance change necessary to cause rotor movement. This capacitance should not exceed 0.35 Pf.

Response-time check. This is a check of the time it takes the indicator pointer to travel from stop to stop. Adjust the tester so that the indicator runs against the FULL stop. Disconnect the unshielded tester lead and check the time required for the pointer to rotate to the empty stop. The response time for the transistorized indicator must be 45 seconds, with a tolerance of +30 percent or −15 percent.

Tank unit bench tests. Bench testing the tank units consists of measuring the capacitance of the tank unit and the compensator individually. To measure tank unit capacitance, ground the center contact of the unshielded compensator connector by temporarily connecting it to the shell of the shielded connector on the unit. When you check compensator capacitance, ground the center contacts of both unshielded tank unit connectors in the same way.

The tank unit and the compensator capacitance must meet the requirements specified in the applicable technical order for that specific unit by part number. If it does not, send the entire tank unit to an overhaul depot. No adjustment for the compensator capacitor and tank unit is authorized at field maintenance activities.

A partial short circuit (high-resistance short) in a tank unit can be revealed by the use of the megohmmeter. If the DC resistance is below the value specified in the applicable technical order, the tank unit must be sent to the overhaul depot.

Exercises (812):

1. Why is it important to observe correct polarities when connecting a fuel-quantity indicator for bench check?

2. What is the purpose of the indicator adjustment check?

3. What is another name for a linearity check.

4. What is the purpose of the zero-signal check?

5. What is the purpose of the dead-spot check?

6. How do you bench check a tank unit?

813. Identify inspection steps, calibration methods and procedures, and troubleshooting techniques for the capacitance fuel-quantity system.

Inspection. The inspection requirements for the capacitance-type fuel-quantity systems are similar to those of other avionic instrument systems components. You must be sure each component is mounted securely and in good overall condition. Check the indicators for cracked cover glass and improper range markings. When the fuel cells are open, check the tank unit electrical connectors for deterioration and improper safetying.

Because of the construction and function of the tank units, regularly scheduled maintenance is not required. There are no provisions for field adjustments. Electrical malfunctions in the tank unit circuit are revealed by the substitution capacitance test. An apparent defect in a tank unit may be only a drop of water in a connector. It may also be a high- or low-resistance path to ground from either electrode, or a defective cable. Therefore, before removing a tank unit, check the cabling and indicator. If the trouble is definitely traced to the tank unit, remove it. Then inspect the tank unit (without assembly) for dents or evidence of damage to the outer electrode. If the insulating varnish is damaged enough to expose the electrode metal, replace the tank unit. Open the drain ports of the tank unit, and check all plastic components carefully for cracks.

Calibration. There are two specific methods for calibrating a capacitance fuel-quantity system. One is the preferred, the other is the alternate method—which is, of course, used only when it is not possible to use the preferred method. You will see why in the next few paragraphs.

Preferred method of adjustment. This calibration method is used with fuel tanks empty. First energize the system and slowly turn the full potentiometer shaft clockwise until the indicator pointer starts to move abruptly toward empty. Then turn it one-half turn in either direction, so that it is at the approximate midpoint of its electrical adjustment range. Next set the empty potentiometer shaft so that the indicator pointer coincides with the zero graduation. NOTE: To avoid gear backlash error, begin by moving the pointer slightly below the value being tested with the push-to-test gates switch and allowing it to move up scale to the test reading. The dry tank units and compensator provide the capacitance input for the system. Disconnect the multipin connector at the rear of the indicator, and connect an adapter harness between the indicator and its mating connector (see fig. 1-21). Using the cables (A, B, and C) packed with the MD-1 tester, connect the tester to the adapter harness. The C1 variable capacitor of the tester is connected in parallel with the tank units, and the C3 variable capacitor of the tester is connected in parallel with the compensator. Set and lock the C3 capacitor at

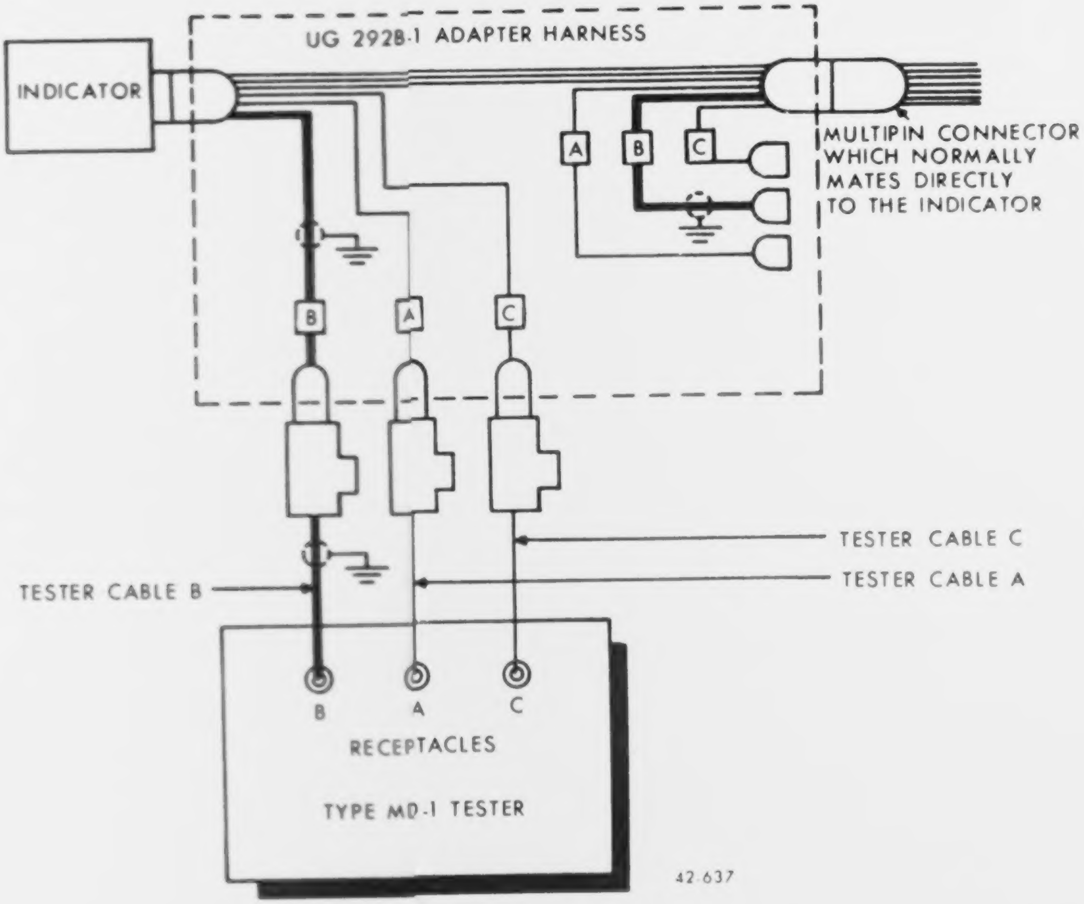


Figure 1-22. Connection for the alternate method of adjustment.

the compensator added capacitance value specified in the -2 maintenance handbook. Set the C1 capacitor at the specified added capacitance value. Adjust the full potentiometer of the indicator until the indicator pointer centers on the last scale mark on the full end of the scale. Now, disconnect the adapter harness and the MD-1 tester and reconnect the indicator, using the system's mating connector. Recheck to see that the indicator pointer is still at zero. If the pointer does not coincide with the zero graduation, repeat both empty and full adjustments as outlined previously.

Alternate method of adjustment. The alternate method of adjustment is used when it is impractical to drain the fuel tanks. First, energize the system and adjust the full potentiometer to its midpoint position as was done at the beginning of the preferred method. Disconnect the multipin connector from the indicator and connect the adapter harness between the indicator and its mating connector. Using cables A, B, and C connect the adapter leads to the tester, as shown in figure 1-22. Set and lock the C3 capacitor at the compensator full capacitance value specified in the -2 maintenance handbook. Set the C1 capacitor at the specified empty capacitance value. Adjust the empty potentiometer on the indicator so that the pointer coincides with the zero graduation. Next, change the C1 capacitor setting of the tester at the specified full capacitance value. Adjust the full potentiometer of the indicator so that the pointer centers on the last scale mark on the dial. Reset the C1 capacitor to the empty capacitance value, and recheck the position of the indicator pointer at zero. If the pointer does not coincide with the zero graduation, keep repeating both empty and full adjustments outlined above until the pointer coincides at both positions. Perform the preferred method of calibration at the next practical opportunity.

Troubleshooting. As you should already know, certain troubles do appear in the electrical circuit at times. When these troubles occur, you should be able to recognize and correct them in the shortest possible time. A thorough understanding of the MD-1 and MD-2A testers will aid you in locating faulty units. It is impossible to cover in this text all of the malfunctions you may encounter on the fuel-quantity system. Table 1-1 outlines the more common troubles, their probable causes, and their remedies. Remember always to use the applicable TO for the specific system on which you are working.

Most fuel-quantity system malfunctions occur because of wiring troubles. Therefore, be very careful when you

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TABLE 1-1
FUEL QUANTITY GENERAL TROUBLESHOOTING CHART

TROUBLE	PROBABLE CAUSE	ISOLATION PROCEDURE	REMEDY
Gage pointer against empty stop or rotates continuously counter clockwise	Defective gage, bridge unit, or amplifier		Replace gage, bridge unit, or amplifier
	Open tank unit lead	Check tank lead and return lead for continuity and loose connector contacts	Repair wiring
	Shorted test switch circuit to ground	Check test switch	Replace switch
	Shorted compensator circuit caused by presence of moisture or foreign materials in the compensator	Drain sumps	Remove moisture Replace compensator tank unit
	Tank units disconnected or poorly connected	Conduct substitute capacitance test Check related cabling and connectors	Repair wiring
Gage behavior erratic	Defective gage, bridge unit, or amplifier		Replace gage, bridge unit, or amplifier
	Intermittent continuity or grounding of tank unit leads	Check cables and connectors in tank unit circuit	Repair wiring
Gage reading is obviously incorrect	Defective gage, bridge unit, or amplifier		Replace gage, bridge unit, or amplifier
	Open compensator circuit	Check compensator circuit for open	
	Low insulation resistance in cables	Check insulation resistance of cables	Repair wiring
	Water in fuel tank		Drain sumps
	Open connection in tank unit or compensator circuits	Conduct substitute capacitance test	Repair wiring Relocate fuel probes
Total fuel quantity gage reads incorrectly	Defective connection	Check all connections to signal summation unit and total fuel quantity gage	Repair wiring
	Total fuel quantity gage out of adjustment		Adjust total fuel quantity gage
	Signal summation unit out of adjustment		Adjust signal summation unit
	Defective total fuel quantity gage or signal summation unit		Replace total fuel quantity gage or signal summation unit
Total fuel quantity gage does not read within 1% of sum of tank gage readouts	Summation unit out of adjustment		Adjust summation unit adjustment screws as needed
Individual gage does not respond to test switch operation	Loss of power to the system the system	Check that circuit breakers are closed	
	Defective amplifier	Check for 28 volts dc and 115 volts ac	Replace amplifier
	Defective gage		Replace gage
	Defective test switch	Check test switch and wiring	

TABLE 1-1

FUEL QUANTITY GENERAL TROUBLESHOOTING CHART (CONT.)

TROUBLE	PROBABLE CAUSE	ISOLATION PROCEDURE	REMEDY
	Grounded amplifier input circuit due to a defective cable or connector	Check shielded cable and connectors between tank units and gage for grounds	Repair wiring
Gage pointer against full stop or rotates continuously clockwise	Defective gage, bridge unit, or amplifier		Replace gage, bridge unit, or amplifier
	Open full adjustment wiper		
	Water in tanks between tank unit electrodes		Drain sump
	Compensator disconnected	Check compensator lead for continuity	Repair wiring
	Shorted tank unit circuit	Check tank lead and return lead for continuity and loose connector contacts	
	Insulation breakdown in shielded cable	Check shielded cable	Repair wiring
Gage does not read zero when tank is drained	Gage out of adjustment		Adjust gage
Gage does not read right amount when tank is full	Gage out of adjustment		Adjust gage

install connectors to the tank units and when you replace the cables. The accuracy and sensitivity of the system depend upon the high-insulation resistance of the coaxial cable (center conductor to shield).

Exercises (813):

1. When you are inspecting a capacitance system and detect an apparent malfunction in a tank unit, what would be your first step in correcting this malfunction?

2. Identify the two methods for calibrating a capacitance fuel-quantity indicating system.

3. When making the empty adjustment, using the preferred method, what provides the capacitance input to the system?

4. When would you use the alternate method of adjustment on the capacitance fuel-quantity system?

5. What is the most important thing to do when troubleshooting a fuel-quantity system on an aircraft?

6. What is the most frequent cause of malfunctions in the capacitance fuel-quantity system?

7. In calibrating a fuel-quantity indicator, from which direction should the test point be approached and why?

814. State how to remove, repair, and install components in liquid quantity indicating systems.

Remove, Repair, and Install Components. In addition to the maintenance fundamentals previously covered, some special procedures must be observed when working on liquid quantity indicating systems.

Indicator. Bonding requirements vary among these systems and must meet TO specifications to insure proper system operation. On some aircraft, a single-point ground for the shielded lead is critical and the indicator must not

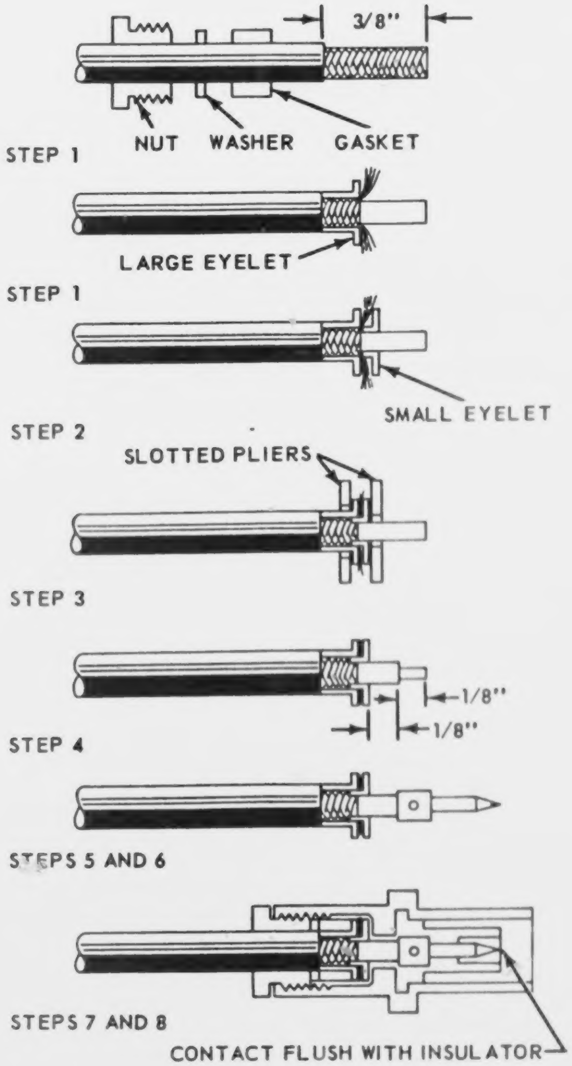


Figure 1-23. Coax connector assembly.

be bonded. Most indicators must be calibrated when they are installed. Handle all gages with extreme care. Sharp impacts may seriously damage the internal components. Always pull the circuit breakers for the circuit before disconnecting a gage. Misaligning the connectors during mating could introduce 115 volts into a fuel tank causing arcing resulting in an explosion.

Tank units. The hazardous nature of the task of removing and replacing fuel probes has caused some commands to assign this job to trained fuel systems specialists. At many installations though, you, the instrument specialist must remove and install them. If they are mounted internally wear only white cotton coveralls, socks and underwear to eliminate any buildup of static electricity which could produce sparks when you touch metal objects. Use brass (nonsparking) tools. Because fuel vapors are intoxicating, especially when inhaled for extended periods, always have a safety observer present at the fuel tank access. Drain the tank and purge it of fuel vapors until the air is safe to breathe. Some fumes will still be present; so, NEVER enter a fuel tank alone.

Do not use electrical equipment inside a fuel tank. TO 1-1-3 lists equipment you may safely use.

Be careful even when you work on externally mounted probes. Although most of them are mounted on or near the top of the tank, some are mounted on the side or bottom. Make sure the fuel level is below the level of the probe before you remove it. Don't damage the seal or the sealing surface. Small nicks or scratches can cause serious leaks. Always disconnect electrical power to the aircraft before removing a fuel probe or opening a fuel tank in any manner.

Splicing. Special handling of splices is required in all shielded wires in liquid quantity indicating systems. The sensitivity of the circuit requires that only an absolute minimum of the signal wires be unshielded. The shields of the coax leads should be connected throughout the circuit. A normal unshielded splice will cause a signal error that exceeds system tolerances. A broken or shorted shield can cause huge errors in the quantity indications.

Connectors. Deterioration, improper handling, and improper assembly of connectors are major causes of problems in capacitance liquid quantity indicating systems. Several different types are used. Because coax connections usually present the most problems we will cover how to assemble them. All such miniature connectors come unassembled so, be careful not to misplace any of the pieces or the assembly instructions. Refer to figure 1-23 as we discuss the assembly procedures.

First, slide the back nut, the washer, and the gasket over the cable. Strip the outer jacket 3/8 inch. Be careful not to nick the braid. Slide the large eyelet over the braid so that it butts against the cut end of the jacket. Comb out the braid and slide the smaller eyelet over the dielectric. Push the smaller eyelet under the braid into the large eyelet. Special slotted pliers can be obtained or conventional pliers can be adapted for this purpose. Cut the dielectric 1/8 inch from the small eyelet being careful not to nick the conductor. Cut off the exposed conductor leaving 1/8 inch. Tin the exposed conductor and the inside hole of the contact. Keeping the contact hot with the soldering iron, slide the contact onto the conductor. Scrape off any excess solder with a knife or a fine cut file. Seat the contact and eyelets into the connector body and install the gasket firmly against the eyelets. Push the washer firmly against the gasket. Hold the connector body stationary and screw the nut into it. Tighten to 30-35 inch pounds torque. When properly assembled and mated with another connector, this type of connection assures continuity of the center conductor and the shield and is moisture tight.

TO 1-1A-14 contains detailed instructions for splicing wires, including coax leads. It also has detailed instructions for assembling all of the commonly used connectors.

Other than repair of wiring and replacement of connectors, the components of liquid quantity systems are rarely repaired in field shops. For those places where these components are repaired, the procedures are best learned through OJT.

Exercises (814):

1. Why should some full quantity indicators be bonded and others not bonded?

2. Why should you pull the circuit breakers before you disconnect a fuel quantity indicator?

3. Why should you not wear nylon or other man-made fabrics inside fuel tanks?

4. How many people are required to perform maintenance inside a fuel tank? Explain your answer.

5. Which type of connector normally causes the most problems in a liquid quantity system?

Utility Systems

UNDER THE HEADING of utility systems, we include position indicating systems, accelerometers, and standby compasses. Although they are not essential for flight, they do perform useful functions and make flying the aircraft easier and safer.

2-1. Position-Indicating Systems

Position indicating systems monitor the position of the landing gear, wing flaps, trim tabs, cowl flaps, exhaust nozzles, lateral trims, crosswind crab and other adjustable or moving controls. The position-indicating systems are necessary because the positions of the control surfaces or components are not always observable by the pilot. Some of these, the landing gear for example, have but two operating positions. The pilot must not only know the position of the gear; but must also know whether the gear is locked in its proper position. Other controls have a wide range of intermediate operating positions. The leading and trailing edge flaps fall into this category. Yet, even here, the pilot must know their exact positions to operate the aircraft safely.

These position-indicating systems usually fall into two categories. Most are based upon the selsyn principle. The word "selsyn" is derived from the term "self-synchronous." However, another type of position indicator becoming more common in today's aircraft incorporates an instrument with a solenoid-actuated rotating card that is controlled by a switch. An example of each is covered in this section.

815. Identify features of the position-indicating system and analyze its operation.

Wing Flap Position-Indicating System. The wing flap position-indicating system typifies the selsyn principle. Two units make up this system. They are an indicator and a transmitter which is mounted on the flap gearbox. A shaft extending from the transmitter connects mechanically to the flap drive system. When the flaps move, this shaft rotates. Wires connecting the transmitter and indicator carry the electrical currents which turn the pointer shaft in the indicator through the same number of degrees that the transmitter shaft rotates. Since both shafts rotate in synchronization, the system is said to be self-synchronous. To get a general understanding of the system's operation, let's closely examine the units.

Transmitter. The transmitter consists of a circular resistance winding with three taps 120° apart. Notice that in the schematic in figure 2-1 the two wipers mounted on the transmitter shaft make electrical contact with the resistance winding at points that are 180° apart. These wipers are rotated by transmitter shaft movement. One of the wipers is connected to the DC bus and the other is grounded to the aircraft through the transmitter case.

Indicator. The electrical mechanism of the indicator (fig. 2-1) is a delta-wound coil connected by wiring to the transmitter. Voltages that vary with the position of the transmitter wipers cause electrical currents to flow in the indicator field coils. The currents through two adjacent coils in the indicator are flowing in such a direction as to set up opposing fields in the laminated ring. As a result, instead of the flux going around the ring, it is forced out of the ring. It must cross the inside space. The path of the flux is shown by the dotted lines through the indicator in figure 2-1. As the voltage at the transmitter taps is varied, the distribution of current in the indicator coils is affected. The direction of the magnetic field flowing across the indicating element is changed. As the magnetic field changes direction, the polarized (permanent magnet) rotor follows it. There are no springs or restraining forces on the rotor. Its movement is independent of the power source voltage. Likewise, since the coils are arranged symmetrically, the rotor position is not affected by the changes in coil resistance that occur with changes of temperature. How accurately the polarized rotor will follow depends upon how accurately the coils and taps are spaced. Therefore the transmitter and indicator in the system must be matched. Many indicators and transmitters are outwardly identical. You must carefully check their part numbers to avoid mismatches.

System Operation. So that you will better understand how the selsyn system operates, let's assign some voltages to the units shown in figure 2-1. You should be able to see that if 28-volt DC power is applied to the power contact arm, the voltage must be dropped between the power contact arm and the ground contact arm. With the contact arms positioned as shown in figure 2-1, tap 1 of the transmitter resistance strip would be at a 28-volt potential. The ground contact arm would be at a 0-volt potential. Since taps 2 and 3 of the resistance strip are each about one-third of the distance between the ground contact arm and the power contact arm, about 1/3 of the applied voltage will be dropped at each of those taps. This means that the voltages felt at the taps will be: tap 1, 28 volts; tap 2, 9 volts; and tap 3, 9 volts.

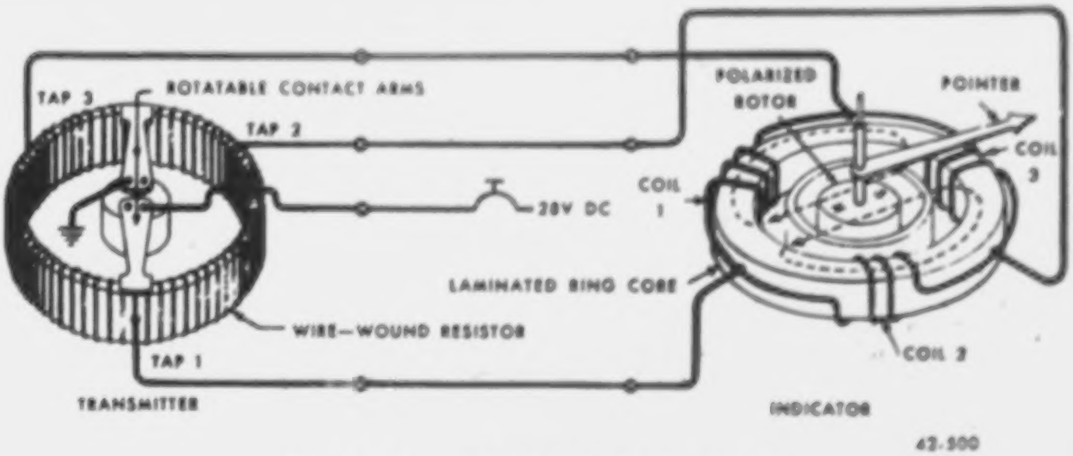

TAP 3
ROTATABLE CONTACT ARMS
TAP 2
28V DC
WIRE—WOUND RESISTOR
TAP 1
TRANSMITTER
POLARIZED ROTOR
POINTER
COIL 3
COIL 1
LAMINATED RING CORE
COIL 2
INDICATOR
42-500

Figure 2-1. Schematic of a typical position indicating system.

Notice that the wires connected to the taps of the transmitter resistance strip are also connected to points between each coil of the indicator. Follow the wire connected to tap 1 across the diagram to where it connects between coil 1 and coil 2 of the indicator. The 28-volt potential from tap 1 of the transmitter will be present at this point. Now follow the wires connected to taps 2 and 3 of the transmitter. The same 9-volt potential of these taps will be applied to these points. With these potentials applied to the indicator coils, let's see what happens. Because both ends of coil 3 are at the same potential (9 volts), no current will flow in coil 3. However, a 19-volt potential exists across coil 1 and coil 2 (the difference between 9 volts and 28 volts). Because of this, current will flow through coils 1 and 2 from the 9- to the 28-volt potential. This creates the magnetic field represented by the dotted lines in figure 2-1. The permanent magnet rotor will align with this field. This causes the pointer to show the position of the wing flaps. As the contact arms are repositioned on the resistance strip, the voltage changes will create a magnetic field change in the indicator and will cause the pointer to show the new position of the wing flaps.

Exercises (815):

1. Describe the main electrical unit of a selsyn position transmitter.

2. What causes the pointer of a selsyn indicator to move?

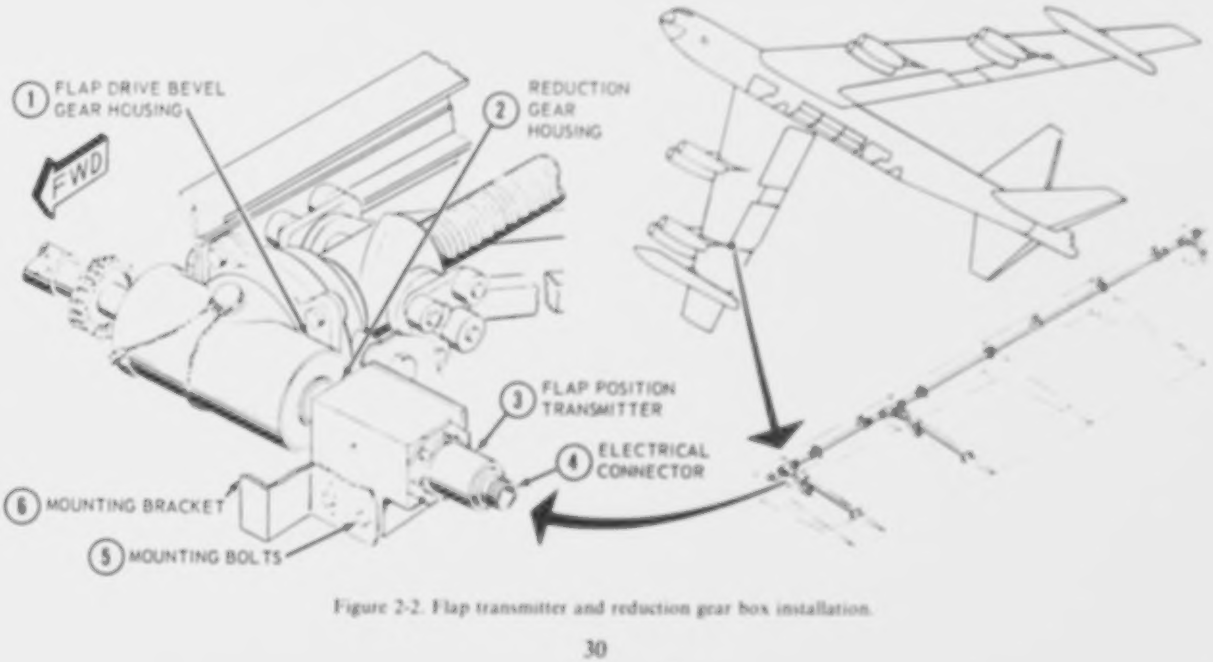

① FLAP DRIVE BEVEL GEAR HOUSING
② REDUCTION GEAR HOUSING
FWD
③ FLAP POSITION TRANSMITTER
④ ELECTRICAL CONNECTOR
⑥ MOUNTING BRACKET
⑤ MOUNTING BOLTS

Figure 2-2. Flap transmitter and reduction gear box installation.

3. Referring to figure 2-1, state how much of the applied voltage is dropped between tap 1 and tap 2 of the position transmitter.

4. Referring to figure 2-1, assume that the transmitter wiper moved clockwise around the resistance strip to align with transmitter tap 2, in which direction would the indicator pointer point?

816. State how to remove and install position indicating transmitters identify inspection and operational check requirements for position indicating systems.

Removal of Components. For coverage of how to remove and install position indicators, review the instrument maintenance fundamentals in Volume 4. Removing and installing position transmitters is a little more complex because there are several different types, styles, and methods of mounting. On some aircraft, the transmitter shaft is turned by reduction gears. On others, it is turned by a mechanical linkage and on some it is turned by a cable and pulley arrangement. The most common method is a direct drive with the transmitter mounted in or on the actuator of the movable surface.

Remove transmitters mounted on a reduction gear box (fig. 2-2) as a unit. This makes it much easier to adjust the system. You will normally have to move the movable surface to gain access to the transmitter. Flap transmitters are usually mounted in the flap well near the flap drive assembly so you should run the flaps full down. Remove the mounting bolts from the reduction gear box mounting bracket and separate the reduction gear shaft from the flap drive housing. After removing the reduction gear unit and transmitter, remove the four transmitter mounting screws and remove the transmitter from the gear housing.

Installation. Attach the transmitter to the gear housing with four mounting screws. Position the transmitter so you can connect the electrical connector to it. Make sure the transmitter case is grounded. Rotate the reduction gear shaft until the indicator pointer is at full down. When you get it within TO tolerance, hold the shaft at that position and mate the reduction shaft with the flap drive. Install the mounting bolts and safety wire the bolts and the electrical connector.

For transmitters mounted in or on the actuator, the actuator usually must be replaced. A specialist from the aerial repair shop will do this.

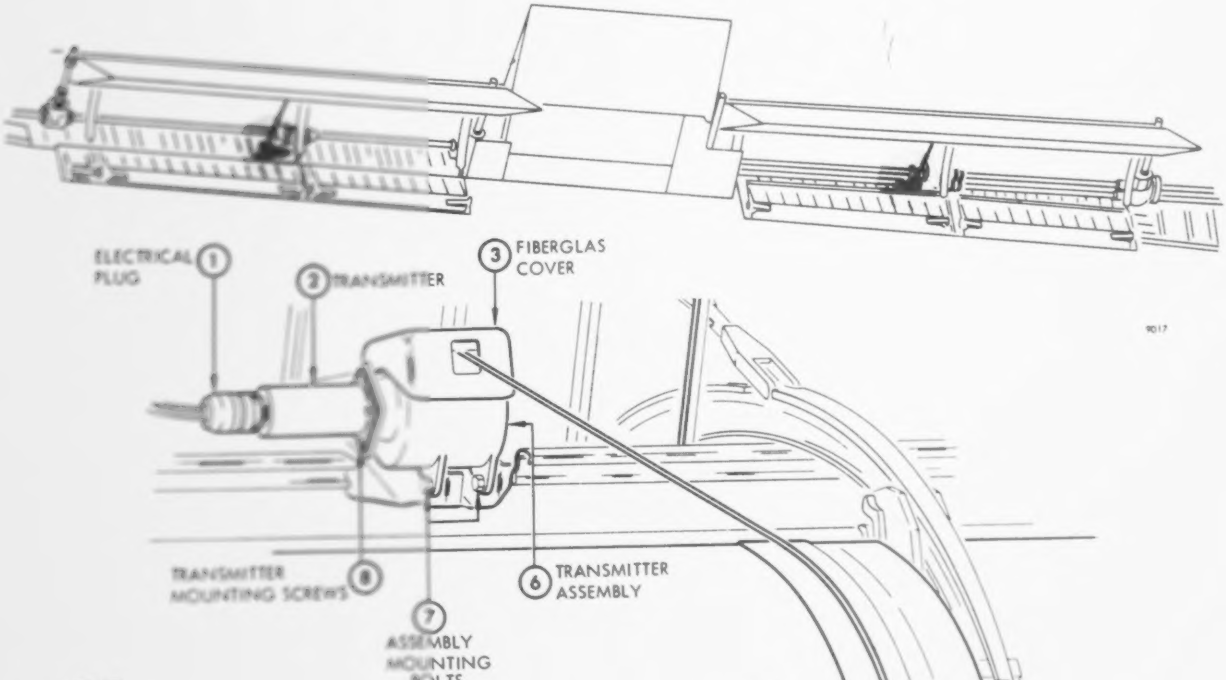


Figure 2-3. Flap transmitter with cable and drum assembly.

Figure 2-3 shows a flap transmitter which is operated by a cable and drum (pulley) assembly. This transmitter alone can be replaced or the whole assembly, including the cable and drum, can be replaced. One of the more important things to remember about installing position transmitters is that they must be bonded to operate.

Inspection. You inspect the same items in a position-indicating system that you would inspect in any instrument system. Be sure the indicator is mounted securely, that range markings are placed properly and that the unit is in good overall condition. Check that the transmitter is mounted securely and is in good overall condition. In addition, check all electrical connectors for tightness and proper safetying.

Operational check. When you perform an operational check you must operate the system for which the position is being measured. Checking a wing flap position system requires two people. You may also have to request assistance from personnel of other maintenance shops. For example, flight line personnel can apply external power to the aircraft. If the wing flaps are operated by hydraulic pressure, hydraulic shop personnel can help by applying external hydraulic pressure. These items will vary with different types of aircraft.

Apply all the necessary power to the aircraft. Station your helper outside the aircraft where he or she can visually check the wing flaps. This is necessary to prevent maintenance personnel or equipment from getting into the path of the moving flaps. The assistant also makes sure the flaps travel to their full UP and DOWN positions. When the observer gives you an all clear sign, you can operate the wing flaps. Check the flap position indicator for a zero percent indication with the flaps up, and 100 percent down when the flaps are full down. The indication from full up to full down should be smooth and accurate. You can follow these procedures to check any position-indicating system on the aircraft.

Exercises (816):

1. Which items would you inspect in a position system? For what conditions?

2. How many people are necessary to safely perform an operational check on a wing flap position indicating system? Why?

3. At which test points do you check the flap indicator for correct indications?

817. Specify troubleshooting and bench check procedures and identify test equipment used.

Troubleshooting, Bench Checking, and Test Equipment. Position-indicating systems are relatively easy to maintain. The components of the system will last a long time. However, we will discuss some of the common troubles with the system, so that you will be better able to maintain it.

The indicator is almost trouble-free. However, after long periods of use, it may become sluggish or sticky. Then you must replace it. The transmitter causes most of the troubles in these systems. The most common troubles are oscillations or a jumping pointer indication, or pointer movement over only half of the indicator range. When these indications are observed, the trouble is usually caused by an open, dirty, or corroded resistance strip in the transmitter. You can check the transmitter by placing an ohmmeter across the pins of the electrical connector and rotating the transmitter shaft. As the shaft rotates, the ohmmeter pointer should show a smooth increase or decrease in resistance. Remember, you will have to change to a different pin on the connector for each segment of the resistance strip. If the indicator pointer fails to move, the most probable cause is a power failure. This trouble, of course, can be checked with a multimeter. If power to the system fails while it is in operation, the pointer will point to the off-scale position.

A multimeter is the most valuable troubleshooting aid for the position-indicating system. There is no common piece of test equipment designed for testing position system components. You can, with the help of the applicable component TO, get a standard transmitter for constructing a bench mockup.

Unless you have a bench mockup for testing the position components, the only component that can be bench checked is the transmitter. This can be done with a selsyn tester. Since so many different types of transmitters are used on the aircraft, it is impossible to list the procedures for even a typical transmitter. You must obtain the TO for the components of the system that you have on your aircraft. Then simply follow the instructions listed in the TO.

Exercises (817):

1. What will be the indication on the position indicating system if power fails?

2. What is the most frequently used piece of test equipment when troubleshooting of position-indicating system?

3. What test equipment is used for bench testing position indicating components?

818. Cite operating characteristics of landing gear position-indicating systems.

Landing Gear Position-Indicating System. The landing gear position-indicating system in most aircraft consists of a DC solenoid-type indicator and two microswitches actuated by the landing gear. Of course, there is normally one system for each gear. The switches (normally spring-loaded open, mechanically actuated closed) are located on the landing gear. The indicators are located on the instrument panel.

Indicator Operation. The indicator consists of a heart-shaped double magnet and two solenoid coils. A pivot in the center of the magnet allows it to rotate in such a way that the open ends of the magnet can enter the open space of the coils. The dial attached to the magnet has three symbols painted on it: a miniature landing gear; which appears when the gear is down and locked; a cross-hatched warning symbol, which is displayed when the gear is moving or is unlocked; and the word "UP," which is visible when the gear is up and locked. The magnet is made so that the two south poles are together at the pivot point; therefore, the ends are both north poles. When either lock switch is closed, current flows through the respective coil to produce a magnetic field. The north pole of the field repels the nearest north pole of the magnet, while the south pole of the field attracts the other north pole of the magnet. This makes the magnet and the attached dial rotate. The direction of rotation depends upon which switch is closed. When neither switch is closed or when power is off, a spring centers the magnet and the cross-hatched warning symbol is displayed.

If a component malfunction causes both switches to close at exactly the same time, or if power is applied after both switches are closed, the indicator will continue to display the cross-hatched warning symbol. In this case, both solenoids are energized, and they exert equal and opposite force on the magnet. The resultant force on the magnet is zero, so it remains stationary. However, if one switch closed first while power is applied to the system, closing the second switch will have no effect on the indicator. The explanation is quite simple. The magnetic field is strong at the center of the solenoid. The force exerted on a pole in this field is much stronger than the force exerted on a pole some distance from the field. Thus, even though the second solenoid tends to pull the magnet back to the center position, it cannot overcome the force exerted by the first solenoid. Consequently, the indication will be unchanged. In some landing gear position-indicating systems, the switching arrangement is slightly different; only one lock switch is used. It closes when the gear is down and locked. A transfer switch in series with the lock switch transfers control between the up-and-down solenoid in the indicator so that the indicator will show the correct symbol.

Exercises (818):

1. When does the miniature landing gear appear on the indicator?

2. When no power is applied to the landing gear position indicator what symbol is displayed in the indicator window?

3. What moves the dial of the landing gear position indicator?

819. List landing gear position-indicating systems inspection and operational check requirements.

Inspection and Operational Check. Inspection requirements for the landing gear position-indicating system consist simply of assuring that the components are mounted securely and are in good overall condition. Be sure all electrical wiring and connections have been installed properly, are tight, and have been safetied.

If it is not feasible to jack an aircraft, you can check the landing gear position-indicating system by operating the proper landing gear microswitches manually. Since this check will be done on the ground, the landing gear will be down and locked. With power to the indicating system, the indicator should show a picture of the gear, indicating that the gear is down and locked. If you open the down switch, the indicator should center and show the crosshatch warning symbol. Hold the down switch open while the up switch is closed. When the up switch is closed, the indicator should show the word "UP." CAUTION: Actuate the switches on the gear *only* if you know for sure that they will operate only the indicating system. If several switches are common to a single-actuating mechanism, the gear might collapse if all the switches are actuated. This might cause injury to you or other maintenance personnel and probable damage to the aircraft.

These procedures will check the indicating system for operation. However, to make sure that the switch mechanical-actuating mechanism is adjusted properly, a retraction test must be done. This is the responsibility of flight line personnel who may get assistance from other shops. Your responsibility is to check the indicating system.

Exercises (819):

1. What are the landing gear position indicating system inspection requirements?

2. If you wanted to operational check the landing gear position-indicating systems on the ground and it is not feasible to jack the aircraft, how would you do it?

3. What caution should you observe when you operationally check a landing gear position-indicating system if you can't jack the aircraft?

820. Identify landing gear position-indicating system malfunction indications with their possible causes.

Troubleshooting and Bench Check. Troubleshooting landing gear position-indicating systems usually involve isolating and locating defective or maladjusted switches, replacing indicators, or repairing or replacing wiring. The only test equipment you'll ordinarily need is a multimeter. Let's examine some of the possible troubles that can occur in the system. The indicator shows the gear unlocked when the gear is actually up or down and locked in position. This fault can have one of several causes. Troubles include lock switches out of adjustment, a defective transfer switch, a defective indicator, or an open circuit in the wiring. If the indicator shows the gear locked when the gear is unlocked, the trouble possibly lies in shorted wiring, grounded or frozen switch contacts, or a defective indicator. To find the particular malfunction, you must check the wiring for shorts or opens. Examine all switches and check their operation and adjustments. If the voltage and continuity checks are correct, then, in all probability, the indicator is defective and should be replaced.

As in the case of most position-indicating systems, no test set is available to check the landing gear system components. You can check the indicator with simple items that are common in most shops—an electrical connector, a single-pole double throw switch, and a 28-volt DC power supply. Connect the +28-volt DC to pin "B" of the connector and connect the ground to the center pole of the switch. Connector pins "A" and "B" are connected to the remaining poles of the switch. The pin designation of the electrical connector may change with different indicators. Always check the applicable TO for the indicator under test for proper pin designation before applying electrical power. Throw the switch from one position to the other and check the indicator's up and down indications. With no power applied the indicator should show the cross-hatch warning symbol.

Exercise (820):

1. Match the landing gear position-indicating system malfunction indication listed in column A with the possible cause listed in column B. Write the correct letter in the space provided. Some possible causes are not used and others are used more than once.

Column A *Malfunction Indication*	*Column B* *Possible Causes*
_____(1) Continuous cross-hatch indication.	a. Shorted power lead.
	b. Shorted up lead.
_____(2) Continuous up indication.	c. Improperly adjusted resistance.
_____(3) Continuous down indication.	
_____(4) Reverse indications.	d. Reversed up and down leads.
_____(5) Frequently sticks in an up or down indication.	e. Improperly adjusted switch.
_____(6) Indicates correctly up but gives no down indication.	f. Open up lead.
_____(7) Indicates correctly down but gives no up indication.	g. Open power lead.
	h. Defective indicator.
	i. Shorted down lead.
	j. Open down lead.
	k. Hermetic seal broken on the indicator.

2-2. Aircraft Accelerometers

In this section we will discuss accelerometer use, construction, operation, and maintenance.

821. Define g-forces and state their effects on aircraft and crewmembers.

G Forces. The maneuverability and speed of a high-performance aircraft causes forces and strains to be imposed upon it. These forces also act upon the crew every time the aircraft makes a change in either speed, direction, or altitude. The most violent of these forces is developed by high-speed loops, turns, and pullouts.

The force that creates more strain on the aircraft and its crew than most others is called centrifugal force. Centrifugal force is that force which pulls outward from a center of rotation. This force, like the force of gravity which pulls us toward the earth, can be expressed in any of the usual force units. However, the unit used to measure it is called the g.

One g is the force exerted by the pull of gravity upon a body at rest. For example, when an aircraft is at rest, the only force acting upon it is gravity; therefore, the normal reading for the accelerometer is 1 positive g. Let's take a closer look at g-force and its effect upon an aircraft and its occupants. Then we will better understand the purpose of the accelerometer and why it is an important flight instrument on high-speed aircraft.

Sitting in a chair, you are pulled down on the seat by the force of gravity. This is a force of 1 g, and it is equal to your weight. In fact, it is your weight, because without gravity (no g's) you would be weightless. Two g's would represent a force equal to twice your weight. If you were to sit on a scale while flying, you would notice that during level flight your weight is normal (1 g). During maneuvers you weigh more or less, depending upon the type of g force that is being applied. Negative g's tend to raise you from the scale, making you weigh less. At two positive g's you have the sensation of being pushed down hard on the seat. At 3 g's you tend to slump; your arms and legs feel as if heavy weights were attached to them, and it is very difficult if not impossible for you to lift them. Furthermore, positive g-force causes the blood to drain from your head. Somewhere between 3 and 4 g's, depending upon the individual, everything begins to appear gray. This is called grayout, and it is caused by the decreased flow of blood to the brain. Then, between 4 and 6 g's most individuals black out completely.

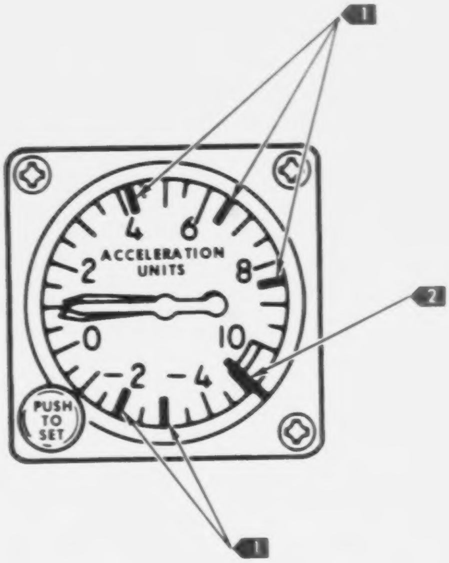
Negative g's on the other hand produce an opposite effect. Your body tends to rise from the seat and blood rushes to your head, causing objects to appear red. As negative g-forces increase, you experience redout and the world disappears from view as a red curtain descends before your eyes. For these reasons crewmembers of high performance aircraft wear anti-g suits that make it possible for them to withstand three or four times the normal g-tolerance.

The effect of g-force on an aircraft depends upon the type of aircraft. It also depends on the duration of the maneuver and on the gross weight and structural strength of the aircraft. Excessive g-loads can weaken or warp structures. They may even cause the loss of a wing or other flight surface. The number of g's an aircraft can safely withstand varies from aircraft to aircraft. Some cargo aircraft, for example, are redlined at 2.5 g's. A modern fighter aircraft may safely tolerate 15 or more g's.

Exercises (821):

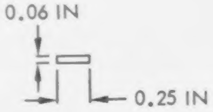
1. What physical effect do excessive positive g forces cause on a person?

ACCELEROMETER

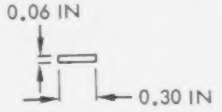


NOTES

1 THE RED FLANGE MARKING STRIPS ARE CUT FROM A RANGE MARKER MATERIAL NUMBER 66 TYPE II R (REF) PER THE FOLLOWING DIMENSIONS:



2 ALL INSTRUMENT RANGE MARKINGS MUST HAVE AN INDEX STRIP (SLIPPAGE MARK) ON THE INSTRUMENT BEZEL AND OUTSIDE THE GLASS. THIS STRIP WILL INDICATE IF THE COVER GLASS HAS ROTATED AND MOVED THE RANGE MARKING TO INCORRECT POSITIONS. PAINT WITH LACQUER, GLOSS INSIGNIA WHITE MIL-L-7178, COLOR NO. 511 PER THE FOLLOWING DIMENSIONS:



3. RED RANGE MARKINGS AT +4.2G, +6.5G, +8.5G, AND AT -1.9G AND -3.0G.

Figure 2-4. Accelerometer.

2. What physical effect does excessive negative g-force cause on a person?

3. What determines how many g's an aircraft can safely withstand?

822. State the purpose of the accelerometer and identify its construction and operating features.

Indicating Accelerometer. The accelerometer (fig. 2-4), often called a g-meter, indicates acceleration action along the vertical axis of an aircraft—or when the aircraft is going into or pulling out of a dive or climb. It does not respond to lateral or longitudinal acceleration. It is graduated in g-units.

Indicator Construction. Several types of accelerometers are used in Air Force aircraft. They all operate on the same principles. The accelerometer we discuss here has three pointers. The main pointer gives a continuous indication of the changes in g-forces as they occur. The two auxiliary pointers indicate the highest plus and the highest minus readings reached during any flight maneuver. The latter pointers remain fixed at their highest readings until they are reset. The pointers can be reset by pushing the reset knob at the lower left-hand corner of the instrument.

The sensitive element and mechanical arrangements, as shown in figure 2-5, represent a typical accelerometer. The drawing is simplified to show the basic operation of the various components. The sensitive element of the instrument is a phosphor bronze weight (A) called the mass. This mass is mounted on a pair of guides or shafts (B), upon which it moves in response to changes in acceleration. A system of pulleys (C, D, and J) transfers the movements to the indicating pointers. D is attached to the end of a shaft which also supports the main pointer (F) and the mainspring (E). When the mass moves, the pulley rotates and turns the shaft.

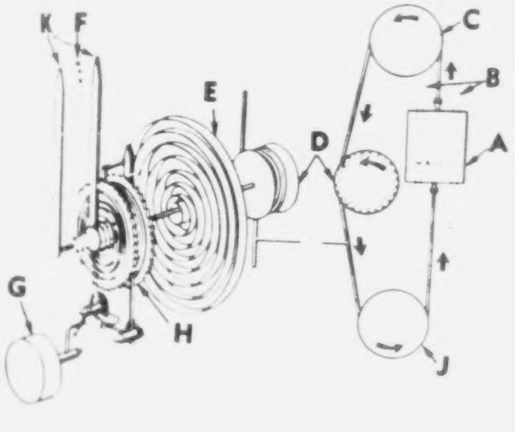
The maximum auxiliary plus and minus pointers (K) are mounted on separate hollow shafts. These shafts are concentric with (have the same center point) and turn with the main shaft. A ratchet and pawl assembly (H) for each pointer limits the turning to one direction only. The amount each of these pointers moves depends on the number of ratchet teeth that pass and are caught by the pawl as the main shaft turns. The reset knob (G) lifts the pawl from the ratchets. Springs then return the pointers to the normal +1 g reading.

Indicator Operation. Accelerometer operation is based upon the principles of inertia and acceleration. Inertia is the tendency of a body at rest to remain at rest or to remain in uniform motion in a given direction, unless subjected to some outside force. Whenever an outside force acts on a body to overcome inertia, there is acceleration. Acceleration is defined as a change in velocity (speed or direction).

The accelerometer compares the forces acting on the aircraft to the force of gravity. When an aircraft is at rest on the ground, the only force acting on it is the force of gravity. Therefore, the accelerometer indicates +1 g. When the aircraft is in straight and level flight and the force of lift is equal to that of the aircraft weight, the only force acting on the aircraft's vertical axis is the force of gravity. Therefore, the accelerometer again indicates +1 g. When the only force that is felt on the mass is gravity, the position of the mass is midway between the top and bottom of the mass guides, as shown in figure 2-5.

When the aircraft begins to dive, the mass (item A in fig. 2-5) tends to continue in the original direction of flight. Due to the law of inertia, the mass moves upward on the mass shafts (B). The mass movement causes pulleys C, D, and J to rotate counterclockwise. When the pulley D rotates counterclockwise, it turns the shaft connected to the main pointer (F), causing the pointer to indicate a minus g-reading. The main spring (E) opposes this motion with a restraining effect that causes the main pointer movement to be proportional to the force acting on the mass.

Negative g-forces are applied to the vertical axis of the aircraft only when it is in the pullover maneuver. When the aircraft dive angle has been established, the negative g-forces no longer affect the vertical axis. The main pointer will return to +1 g. As the aircraft pulls out of the dive, forces are again exerted on the mass. The mass moves downward and the main pointer indicates positive g-forces. After the aircraft levels out from the dive angle, the accelerometer reading returns to +1 g. This indicates that the mass has once again returned to the midpoint on the mass shafts and that the only force being exerted on the mass is the force of gravity.



32 865

A. Phosphor bronze weight
B. Guides
C. Pulley
D. Pulley
E. Mainspring
F. Main Pointer
G. Reset knob
H. Ratchet and pawl assembly
J. Pulley
K. Auxiliary pointers

Figure 2-5. Schematic of an accelerometer.

Exercises (822):

1. What does the accelerometer indicate?

2. What is the purpose of the two auxiliary pointers on the accelerometer?

3. What determines the amount of movement of the auxiliary pointers on the accelerometer?

4. What does the accelerometer indicate when the aircraft is flying straight and level? Why?

5. When is the only time negative g-forces are applied to the vertical axis of the aircraft?

823. Cite the reading on an accelerometer when the reset button is pushed and describe what you would do when you remove an accelerometer from an aircraft.

Inspection and Operational Check. When inspecting the accelerometer, check to see that the auxiliary pointers indicate +1 g when you push the reset knob. Be sure the push-to-reset knob operates freely and that the auxiliary pointers move back to home position. Make sure that the cover glass is clean and intact and that the paint on the dial and pointers is not cracked, chipped, or discolored. Check that the main pointer rests on the +1 g unit. You can't perform a satisfactory operational check on this indicator. The most accurate method we have in the field is to hold the accelerometer in a normal mounting position (dial vertical and 1 g mark at the 9 o'clock position.) The primary pointer should read +1 g after light tapping. Hold the accelerometer with the dial horizontal. It should indicate zero g's after tapping. Then hold the accelerometer with the dial vertical again but with the 1 g mark at 3 o'clock (upside down). It should read -1 g. Flight line maintenance is limited to replacement if the accelerometer malfunctions. It must always be mounted so that it will be horizontal in normal flight attitude. This sometimes requires the use of beveled spacers. A copper or brass bonding strap is sometimes used under one of the mounting screws to ground the lighting fixture. If it is required, be sure the strap and its contacting surfaces are clean to assure good contact. On many of the smaller aircraft, the accelerometer must be range marked as shown in figure 2-4.

Maintenance. If the pilot thinks that this indicator is not working properly, replace the instrument with a new one. Before you install an indicator, be sure to turn the lockscrew on the rear of the new instrument to the UNLOCK position—otherwise the instrument won't operate. Always lock the mechanism of the accelerometer being removed to prevent further damage to the mechanism during handling and shipping.

Troubleshooting. Because the accelerometer is self-contained, all you can do is insure that the mechanism is unlocked. If the instrument does not operate properly, send it to the depot for overhaul maintenance and install a new instrument.

Bench Check. The checking, testing, and calibrating must be performed at depot, where they have the required test equipment. This test equipment is not authorized at field level.

Exercises (823):

1. When you are inspecting the accelerometer and you push the reset knob, what should the main pointer and the auxiliary pointers read?

2. When removing the accelerometer from the aircraft, what should you do to prevent damage to this indicator?

2-3. Direct Reading Compass

The pocket compass, most familiar to us, uses a freely rotating magnetized needle that always points to magnetic north. This method of determining directions, although not precisely accurate, is so reliable that a similar instrument is required in all aircraft.

824. State how a magnetic compass operates and specify maintenance and compensation procedures.

Standby Magnetic Compass. All Air Force aircraft must have a direct reading magnetic compass for emergency use if the navigation system fails. It is used for short intervals only. The standby magnetic compass (fig. 2-6) continuously indicates the direction the aircraft is headed relative to magnetic north by means of a "floating" graduated card that is read against a fixed reference point (lubber line). The card element, graduated in 5° increments to represent horizontal angles, floats in a compass fluid. The cardinal (major) headings are indicated by N., E., S., and W. Each 30° (except for the cardinal headings) is indicated by a number corresponding to the angle.

A system is incorporated in the compass to compensate for deviations in the earth's magnetic field. This compensating system contains two sets of permanent bar magnets that are adjusted by two screws (shown in fig. 2-6) located under a cover plate on the front of the instrument. These adjustment screws are marked N.-S. and E.-W. The compass is internally lit by a 28V DC light bulb.

The magnetic standby compass is mounted in the cockpit in an area that is relatively free of magnetic interference. Normally, this is the upper center portion

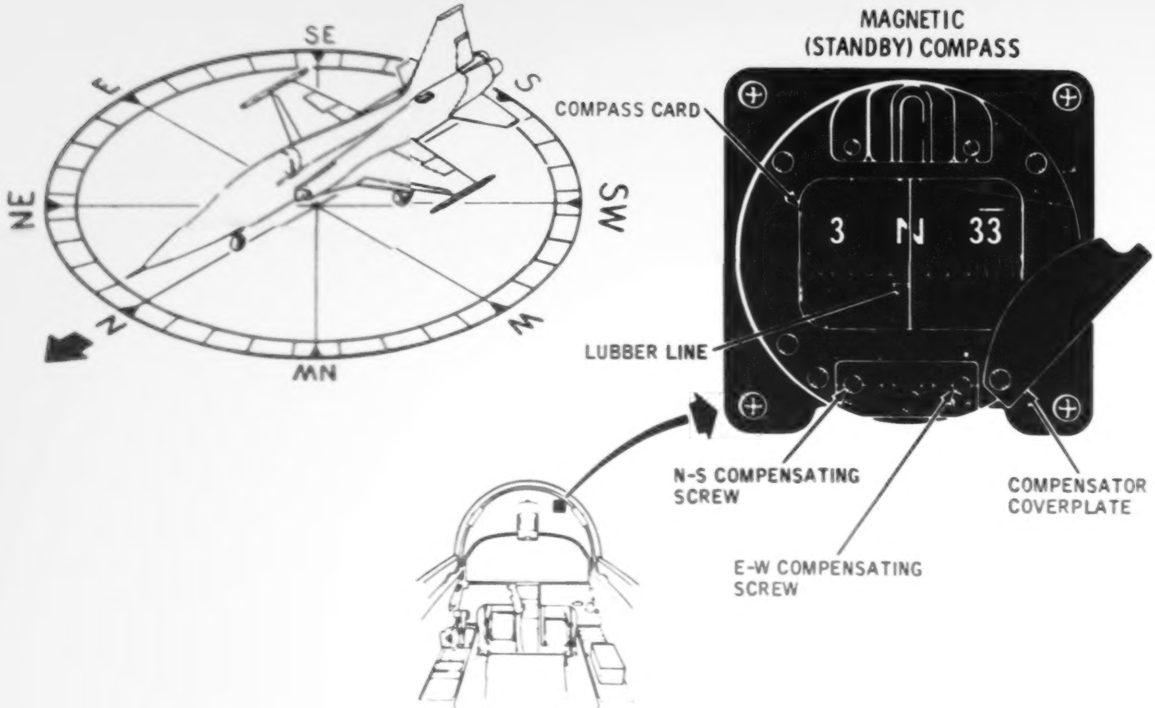


Figure 2-6. Standby magnetic compass.

of the windshield. Maintenance consists of replacing and compensating the compass and replacing the light bulb.

To replace the compass simply remove the mount screws and disconnect the electrical connector and install another compass in its place. Use nonmagnetic (brass) hardware and tools when you install or adjust the magnetic compass.

Compass Swing Procedures. All magnetic compasses require swinging when they are installed and when a major change is made in the aircraft equipment or armament, or when the pilot suspects that the compass is in error. Before you compensate the compass, make sure that no ferrous metal (metal containing iron) is in the area around the compass. Metals containing iron alter the normal direction of the lines of force (flux) of the earth's magnetic field in the same way we use those metals to control the flux in a transformer. The easiest way to detect such ferrous materials is with a magnet because these materials are attracted to a magnet.

You can compensate the compass only in a designated compass swing area (compass rose). This area should be flat and isolated from buildings, railroad tracks, power lines, iron concrete-reinforcements, and other ferrous metals which affect the earth's magnetic field.

You must make a heading check at each cardinal heading to determine how much the compass is deviating before you can compensate for that error. You can determine the deviation only by comparing the indicated aircraft magnetic heading to the actual aircraft magnetic heading. Deviation, then, is the difference between the actual magnetic heading of the aircraft (as indicated by the reference) and the compass reading.

Align the aircraft on the desired magnetic headings before you try to compensate the compass. Using the compass rose gives the most accurate settings; however, you can use a sighting compass or a transit. Also, any aircraft which has had its remote compass system swung electrically can have the standby magnetic compass swung against the calibrated system. If this method is used, the aircraft may be taxied around in an area large enough to rotate the aircraft; or the standby compass can be swung during flight by the aircrew against a calibrated remote compass system. Regardless of which method is used you, as the instrument specialist, must have a thorough understanding of how it is done. Even if the flight crew swings it in flight, you will normally have to provide them with a nonmagnetic screwdriver and instruct them on how to accomplish the swing. In this case, you should be knowledgeable enough to answer any questions they may have.

In flight, the magnetic headings can be obtained from a calibrated remote compass system or determined from celestial bearings taken. On the ground, however, you determine the magnetic headings with a sighting compass.

The sighting compass is a standard compass in which the compensator assembly is replaced with a sighting device. To use it, you stand at least 50 feet in front of the aircraft in a suitable swing location. Then align the sighting compass with the longitudinal axis of the aircraft. Make reference to any suitable pair of in-line objects (such as the radio mast and the vertical stabilizer) along the longitudinal axis of the aircraft. The reading on the sighting compass is then the magnetic heading of the aircraft. This is a reciprocal heading if the magnetic polarity of the sighting compass has not been reversed, so you either add 180° to the reading or subtract 180° from it to determine the magnetic heading of the aircraft.

It is customary for the observer to stand in front of the aircraft because most sighting compasses have the magnets reversed. The compass indicates the actual aircraft heading with the magnets reversed. In this case, it is not necessary to apply a 180° heading correction. Compasses that have the magnets reversed are painted red to prevent inadvertent installation in the aircraft.

Requirements. You will normally need two more people to help you swing a standby compass—a pilot and another specialist. One of you instrument specialists has to be in the cockpit to record, compute, and adjust the compass. Neither person should have any magnetic materials such as tools, pocketknives, mechanical pencils, metal wrist bracelets, eyeglasses with metal frames, or head sets. The specialist on the ground uses a sight compass to align the aircraft to each of the four cardinal headings in turn. To do this, he or she uses hand signals to help the pilot properly align the aircraft on the various headings. He or she also uses hand signals to indicate to the specialist in the cockpit how many degrees the aircraft is misaligned with a heading. For example, no fingers indicates perfect alignment, one finger pointing up indicates a positive 1° error, and two fingers pointing down indicates a negative 2° error. For example, you need the aircraft lined up on North (360° or 0°); your helper is pointing three fingers down. This means that the pilot did not get the aircraft lined up at exactly 360°, but was shy 3°. The actual aircraft heading is 357°. If the cardinal heading on the sight compass is to the right of the lubber line, the error is positive. If it is to the left, it is negative. The amount of misalignment is the number of degrees difference between the cardinal heading and the lubber line.

Cardinal heading check. The pilot turns the aircraft to each heading using the remote compass as a reference. All engines and electrical equipment are operating to simulate, as much as possible, actual flight conditions. You need every normal possible cause of deviation to be at its maximum. At this time, the specialist in the cockpit nulls the compensator screws by turning them until the dot on each screw is directly in line with the dot on the case. The specialist outside checks the alignment of the aircraft at magnetic north and indicates the amount of error to the specialist in the cockpit. Assume that the standby compass is indicating 006.5° and the specialist outside has indicated zero error for this heading. Log these indications in the appropriate columns on the DD Form 1613 as shown in figure 2-7. Notice that in column 1 (Actual Head) at magnetic north the specialist recorded the actual heading of the aircraft (the desired heading of 000° plus no misalignment). Also in column 2, he or she recorded the reading of the aircraft compass (006.5°).

Next, the pilot aligns the aircraft toward magnetic east, then south, and then west. Log the aircraft standby compass reading and the actual aircraft heading at each of the cardinal headings as this specialist did at magnetic north. Compute the deviation by algebraically subtracting the compass reading from the actual magnetic

	Compensating Swing			Residual Swing	
	Actual Head (M)	Aircraft Comp.	Dev'n	Actual Head (M)	Aircraft Comp.
N 000	000	006 1/2	−6 1/2	000	359
				045	045
E 090	090	090	0	090	091
				135	134
S 180	180	175 1/2	+4 1/2	180	179
				225	225
W 270	270	276	-6	270	271
				315	316
	(1)	(2)	(1)-(2)	(3)	(4)

If swinging compass used ahead of aircraft add or subtract 180 degrees.

$$\text{Coeff. C} = \frac{\text{N-S}}{2} = \frac{(-6\tfrac{1}{2})\text{-}(+4\tfrac{1}{2})}{2} = \frac{-11}{2} = -5\tfrac{1}{2}$$

$$\text{Coeff. B} = \frac{\text{E-W}}{2} = \frac{(0)\text{-}(-6)}{2} = \frac{+6}{2} = +3$$

$$\text{Coeff. A} = \frac{\text{N}+\text{E}+\text{S}+\text{W}}{4} = \frac{(-6\tfrac{1}{2})+(0)+(+4\tfrac{1}{2})+(-6)}{4} = \frac{-8}{4} = -2$$

Swung		Compass By:	
TO FLY	STEER	TO FLY	STEER
N	359	180	179
15		195	
30		210	
45	45	225	225
60		240	
75		255	
90	91	270	271
105		285	
120		300	
135	134	315	316
150		330	
165		345	

Figure 2-7. Front view of a compass correction card, DD Form 1613.

heading of the aircraft. Notice in column 1 of figure 2-7 that the pilot stopped the aircraft exactly on the desired cardinal headings of 000, 090, 180, and 270 degrees. Also notice in column 2 that the aircraft compass readings are 006.5° at 000.0°, 090° at E., 175.5° at 180°, and 276° at 270°. From these readings, let's compute the deviation at the four cardinal headings. If the actual aircraft heading is less than the standby compass reading, the error is negative. If the actual magnetic heading is greater than the compass reading, the error is positive. This simply means that the negative error must be *subtracted* from the aircraft compass reading for the aircraft to actually fly at the desired magnetic heading. If the error is positive, it must be *added* to the compass reading to actually fly at that magnetic heading. Notice, in the Dev'n column of figure 2-7, the deviation at each cardinal heading.

Exercises (824):

1. What is the purpose of the aircraft magnetic compass?

2. What reference point is used to read the standby compass?

3. Describe the compass card in a standby magnetic compass.

4. What are the components of the compensating system in a magnetic compass?

5. Where is the aircraft magnetic compass usually located?

6. What type of tools must you use to install or compensate a standby compass?

7. What conditions must exist before you can compensate a compass?

8. What are two methods for determining magnetic heading?

9. Why are some standby compasses painted red?

10. What is the minimum number of people needed to perform a compass swing?

11. What type of material should you avoid carrying when you swing a compass?

12. When should the compensating magnets of a standby compass be nulled so the compass can be compensated?

13. What form is used to record the readings taken during a compass swing of the standby compass?

14. How do you determine what sign to put before the deviation of a standby compass?

825. Given actual magnetic headings and standby compass readings, compute the corrections to apply to a standby compass and state how to complete a compass correction card.

Compensation Swing. We can never completely eliminate the errors in a magnetic compass. This is one reason why they are for emergency use only. Even then they should be used only for short intervals. However, we can reduce the errors so the compass is useable. We will discuss the coefficient method of compensation.

Math. Before we get into compensating the compass, let's review the three algebra rules you need to know to solve the formulas using the coefficient method.

Rule No. 1 states that when you add like signs, you simply add the numbers and keep that sign. For example, (-6) + (-4) = -10, or (+4) + (+6) = +10. Rule No. 2 states that when you add unlike signs, you subtract the smaller number from the larger number and keep the sign of the larger number. For example, (-6) + (+4) = -2, or (-4) + (+6) = +2. Rule No. 3 states that when you subtract algebraically, you always change the sign of the subtrahend and add, following rules No. 1 or No. 2. For example, (-6) - (+4) = -10, or (-6) - (-4) = -2.

You substitute the deviation values in place of the N, S, E, or W symbols in the coefficient formulas (C, B, and A) on DD Form 1613 and solve for each. When coefficient C in figure 2-8 is solved, you have a -4° correction. That is, when you subtract +6 from -2, the difference is -8; and when you divide -8 by 2, the correction is -4°. Also, notice in figure 2-8 that the correction for coefficient B is -4° and for coefficient A it is +3°.

Correction swing. You are ready for the correction swing. At this time, the pilot turns the aircraft toward magnetic north. You apply coefficient A (from the DD

	COMPENSATING SWING			RESIDUAL SWING	
	ACTUAL HEAD *(M)*	AIRCRAFT COMP	DEV'N	ACTUAL HEAD *(M)*	AIRCRAFT COMP
N 000	358	000	-2	000	001
				045	045
E 090	092	092	0	090	089
				135	135
S 180	185	179	+6	180	181
				225	225
W 270	276	268	+8	270	269
				315	315
	(1)	(2)	(1) - (2)	(3)	(4)

IF SWINGING COMPASS USED AHEAD OF AIRCRAFT, ADD OR SUBTRACT 180 DEGREES

Coeff $C = \frac{N-S}{2} = \frac{(-2)-(+6)}{2} = -4$

Coeff $B = \frac{E-W}{2} = \frac{(0)-(+8)}{2} = -4$

Coeff $A = \frac{N+E+S+W}{4} = \frac{(-2)+(0)+(+6)+(+8)}{4} = +3$

COMPASS Standby			
SWUNG 5/02/81		BY Sight	
TO FLY	STEER	TO FLY	STEER
N	001	180	181
15	016	195	196
30	030	210	210
45	045	225	225
60	060	240	240
75	074	255	254
90	089	270	269
105	104	285	284
120	120	300	300
135	135	315	315
150	150	330	330
165	166	345	346

Figure 2-8. Completed DD Form 1613.

Form 1613) to the aircraft compass. The error determined by coefficient A is installation or index error. This is an average deviation error of the four cardinal headings. You can correct it by shimming the compass case. You must algebraically add the installation error to the compass reading. This adjustment corrects installation error throughout 360° of azimuth.

Let's assume that the aircraft compass is reading 359° at the magnetic north heading. However, the actual aircraft heading (along the longitudinal axis of the aircraft) is 357° (359° - 002° = 357°). As you recall, the error at the magnetic north heading was a -2° during the compensating swing. You shim the magnetic compass until it reads 002° (359° + 003° = 002°). After adjusting for installation error at magnetic north, the deviation errors at the other cardinal headings change by the same amount. For example, at magnetic north heading (000°), before adjusting for installation error, the aircraft compass reads (002°), or has a -2° deviation. However, after adjusting for installation error, you added a +3° correction to the compass reading. At magnetic north heading, the aircraft compass now reads 005°, or a deviation of -5°. Consequently, at cardinal headings, the deviation error at east (90°) changes to -3°. At south (180°), it changes to +3°, and at west (270°), it changes to +5°.

Next, add coefficient C to the compass reading by adjusting the N-S screw while the aircraft is at magnetic north heading. Notice on figure 2-8 that the correction for coefficient C is -4°. Therefore, adjust the N-S screw until the aircraft compass reads 358° [002° + (-4°) = 358°] Remember that there was a 3° difference between the actual aircraft heading (357°) and the magnetic heading (000°). Therefore, the aircraft compass would read 001° at magnetic north.

When you performed the coefficient C adjustment at magnetic north, the deviation error also changed at magnetic south. However, the error change at magnetic south is opposite to the error change at magnetic north. When the aircraft is flying a magnetic south heading, the aircraft compass indicates 181° (174° + coefficient A (+ 003°) = 177° + coefficient C + (004°) = 181°).

The aircraft is next moved around to the magnetic east heading (90°). At this time, add coefficient B to the aircraft's compass by turning the E-W screw. The coefficient B adjustment corrects east and west headings just as the coefficient C adjustment corrects the north and south headings. These adjustments have little or no effect on each other. Consequently, after the three coefficients have been adjusted, this aircraft's compass should read within the TO tolerance at all magnetic headings. At this point, the aircraft is ready for the residual swing. Also, you have information to complete the pilot's correction card, DD Form 1613.

Residual Swing. The pilot's correction card, DD Form 1613, is filled in while you perform a residual swing. The procedure for the residual swing is identical to that followed during the compensating swing except that you must record the actual magnetic heading and standby compass reading at each 45° heading. It is the same as far as positioning the aircraft is concerned. Enter the results of this swing in the appropriate columns (3 and 4) of DD Form 1613. Use them as the basis for determining the various compass headings indicated on the detachable portion of the form.

The front side of the DD Form 1613 is illustrated in figures 2-7 and 2-8. Put the aircraft standby compass readings in the steer column of the detachable portion of the form by each of the appropriate eight headings used in the residual swing. In the very top block of the detachable form, identify the type of compass or compass system you are recording. This form is used also for some remote compass systems. In the Swung block, put the date the compass was swung. In the next block, By, identify the reference used in the swing. Simply write in sight if you used a sight compass or N-1 or J-4 if you swung it against one of those remote compass systems.

The detachable card is placed in a holder near the aircraft's standby compass. It shows the headings toward which the pilot must steer the aircraft to maintain a course. The balance of the form is kept on file in the avionics instrument shop.

Exercises (825):

1. The following data represents the compass deviation error observed during a compass swing:

Cardinal Heading	*Master Compass*	*Aircraft Compass*
N	355°	003°
E	091°	085°
S	183°	183°
W	265°	271°

Solve for:
   (1) Deviation errors at the four cardinal headings.
   (2) Coefficient A, C, and B.
   (3) Minimum deviation of this aircraft compass after adjusting for the coefficients.

2. When is the pilot's compass correction card filled in?

3. What does the compass correction card tell the pilot?

Flight Data Recording Systems

FOR MANY YEARS, the use of recording devices was limited to experimental aircraft and other special circumstances. It was not thought necessary that flight data recorders should complement the instrument systems installed in all of our aircraft. However, because our aircraft have become more sophisticated and the range and flight durations are constantly increasing, flight data recorders are now being installed in most Air Force aircraft. These devices are installed in modern aircraft before they leave the factory. TO modifications updated most of our older aircraft. All aircraft eventually will have some type of flight data recording system.

These recorders are electronic devices that require the most precise maintenance available. The maintenance you can perform on these units will depend upon the equipment you have available. It also depends upon the policies of the organization to which you are assigned. Flight-line operational checks can be performed using test equipment compatible to your type of aircraft. The procedures for the operational checks and test equipment hookup can be found in the applicable aircraft TOs. Some aircraft will have a ground test switch to allow you to perform preflight operational checks. Several types of recorders are installed in different Air Force aircraft, and the procedures for loading the magazines are different. If you must load the magazine with a new recording medium, consult the applicable technical order for the recorder unit that you will load. The technical order will give step-by-step procedures to guide you throughout the magazine-loading task.

3-1. Flight Data Recorder.

One type of device commonly used to record flight data is an airborne oscillographic, scriber-type recorder. It permanently records four kinds of in-flight information. The aircraft's heading, altitude, airspeed, and vertical acceleration (G-units) are scribed onto a metal foil. A magazine assembly contains this recording medium (the metal foil) and protects it from exposure to fire, shock, and water.

826. Identify the flight data recorder system in terms of its design, features and function.

System Components. The flight data recorder system consists of a recorder unit, a magazine, and an acceleration sensor. The system may also contain a test switch and a recorder-inoperative light, depending upon the aircraft in which the recorder system is installed. The recorder unit is completely automatic and has no control switches.

The system uses 115V AC and 26V AC from the aircraft's power supply. The AC power is normally taken from an emergency or isolated AC bus that will remain powered in the event of electrical power failure on the aircraft.

Figure 3-1 is a block diagram of the system components. It also shows the external power and signal source inputs.

Recorder unit. Study figure 3-1. Notice that signals from the aircraft compass system and the accelerometer are supplied to the recorder. The compass signal is used in the recorder's heading channel. The accelerometer signal is used in the vertical acceleration channel. These electrical signals are provided through an electrical connector on the rear of the recorder case. Pitot and static pressures are supplied from the aircraft's pitot static system. These pressures operate the airspeed and altitude channels.

Magazine and recording medium. The magazine, which holds the recording medium, is installed through a hinged plastic door on the front of the recorder unit. The recorder has a time-remaining indicator that represents the amount of recording medium remaining in the magazine and an elapsed time indicator that represents the total length of time the recorder has operated since production or overhaul.

The recording medium is a metal-foil material. It has holes in its edges similar to movie camera film. There are no reference marks on the medium; the values of the scribe marks made on the medium by the recorder must be checked with a scale or overlay. Each recording medium is approximately 150 feet long and will record for approximately 600 hours. After a new medium has run for 300 hours it is taken from the take-up spool position and placed in the supply spool position for the next 300 hours, so there will be scribe marks on both sides of the medium.

Test switch. Notice in figure 3-1 that the flight data recorder 115V AC power is routed through contacts of the external and auxiliary power contactor. When the aircraft is on the ground with external power connected or when the aircraft's auxiliary power unit (APU) is being used, the contacts will be open. This open condition will prevent the recorder unit from operating while ground maintenance is being performed on the aircraft. Notice

728

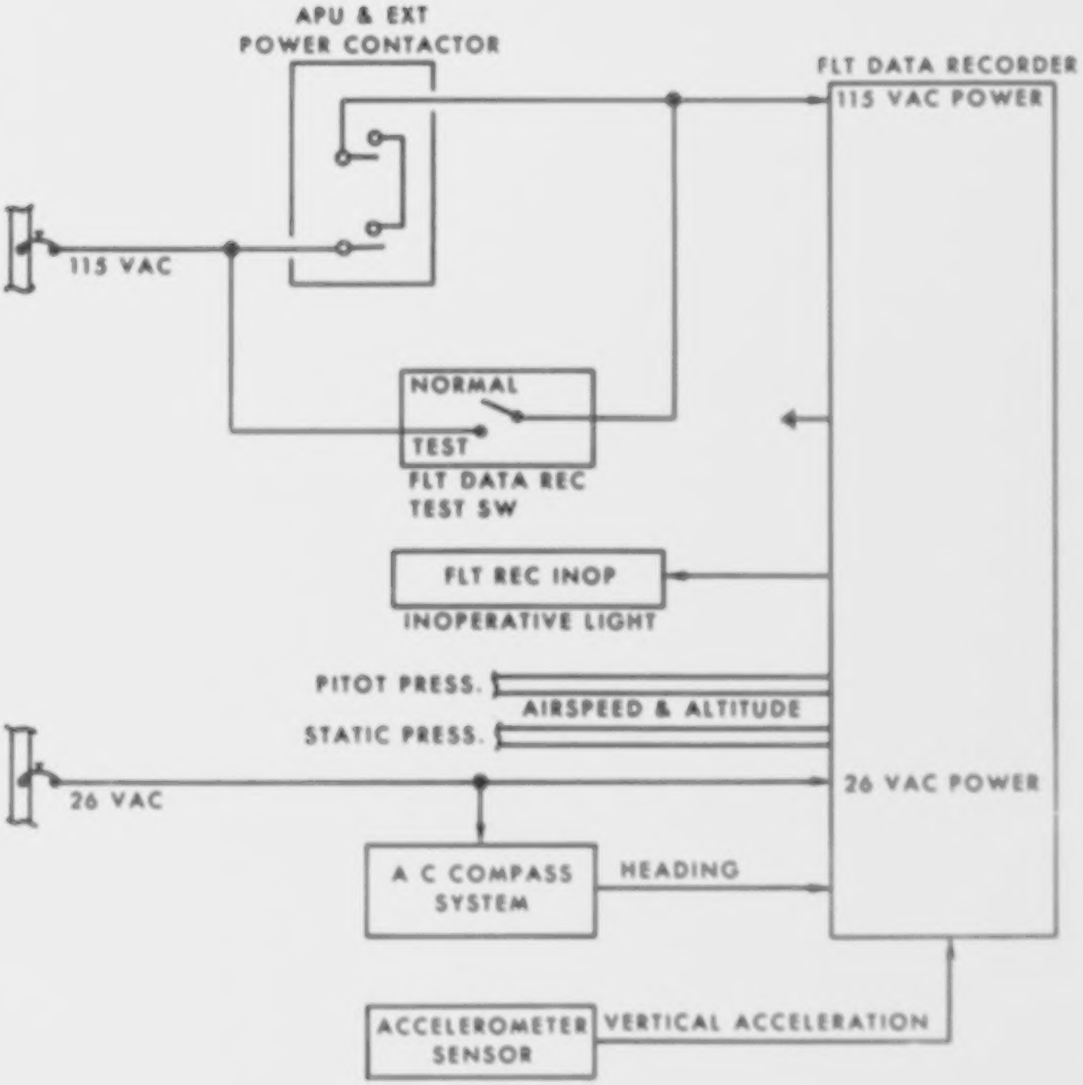

APU & EXT
POWER CONTACTOR
FLT DATA RECORDER
115 VAC POWER
115 VAC
NORMAL
TEST
FLT DATA REC
TEST SW
FLT REC INOP
INOPERATIVE LIGHT
PITOT PRESS.
AIRSPEED & ALTITUDE
STATIC PRESS.
26 VAC
26 VAC POWER
A C COMPASS
SYSTEM
HEADING
ACCELEROMETER
SENSOR
VERTICAL ACCELERATION

Figure 3-1. Flight data recorder system schematic.

that the test switch will bypass the external APU power contactor when it is set to TEST position. This switch allows ground operation checks of the recorder.

Flight data recorder-inoperative light. The recorder-inoperative light is located in the aircraft cockpit. It warns the pilot if the recorder unit is not functioning. The light is illuminated by a power relay in the power supply of the recorder.

Accelerometer (Acceleration sensor). As you learned earlier the accelerometer is a self-contained, sealed unit mounted near the aircraft's center of gravity. It detects vertical acceleration forces within a range of -3G to +6G. The output from the sensor is a 400-Hz signal. The signal amplitude varies with the rate of acceleration force. The phasing of the signal varies with positive or negative acceleration. (Positive acceleration is above +1G and negative is below +1G.) On the side of the sensor is painted an arrow which must point upward when the sensor is installed.

Exercises (826):

1. Name the five units that may make up the flight data recorder system.

2. To which power bus on the aircraft is the flight data recorder system usually connected?

3. What are the sources of the signals applied to the recorder unit?

4. How does it happen that scribe marks are drawn on both sides of the recording medium?

5. Why is the flight data recorder 115V AC power routed through the contacts of the external and auxiliary power contacts?

6. Which component warns the pilot that the recorder unit is not operating?

7. What are the operational limits of the accelerometer?

827. State how the flight data recorder operates and differentiate between the channels.

Recorder Operation. As we have indicated, a permanent record of the aircraft's in-flight information is engraved on the recording medium by scribes in the recorder unit. This medium travels at a constant controlled rate in order to provide an accurate time base. A constant-speed timing and actuating motor that drives the take up spool controls the rate at which the medium is allowed to advance. A frictional drag force in the supply spool prevents slack between the supply and take-up spools.

The scribes, which record heading, airspeed, and altitude, are periodically forced against the recording medium by a single cam-actuated pressure bar. This information appears as a dashed line on the medium. Acceleration is recorded continuously and is not affected by the pressure bar. Static pressure is received by a sensor chamber in the recorder and acts on an evacuated diaphragm. Contraction and expansion of the diaphragm position the altitude scribe. Pitot and static pressures are compared in the airspeed sensor unit of the recorder. A diaphragm senses the differential pressure and positions the airspeed scribe.

Heading information is recorded by two scribes. One is a 2-position, solenoid-actuated scribe, and the other is a variable-position heading scribe. Variable headings between zero and 360° may be recorded. The 2-position scribe indicates which of the two heading scales to read. This scribe engraves an upper mark for northerly headings and a lower mark for southerly headings.

Vertical acceleration channel. The vertical acceleration channel is a closed servoloop. Its output continuously follows the accelerometer output. Notice in figure 3-2 that the excitation voltage for the accelerometer is supplied by the recorder power supply.

The accelerometer output is supplied to the summing junction of the recorder, as shown in figure 3-2. This signal is compared to the signal from the induction potentiometer. If these two signals are equal and in phase, the servoloop is nulled and the voltage amplifier feels no error signal. When the aircraft makes a sudden nose-up maneuver, a positive G signal will be produced by the accelerometer sensor. Now the signals in the summing junctions will not be equal. The difference between these signals will be the error signal that is amplified. This signal will cause the servomotor to drive. Following the flow arrows in figure 3-2, you will see that the motor will position the induction potentiometer to null the error signal. At the same time, the motor positions the scribe arm. Thus, an instantaneous indication of acceleration is continuously provided by the scribe on the recording medium, and a rate feedback signal is produced by the motor generator to stabilize the servoloop.

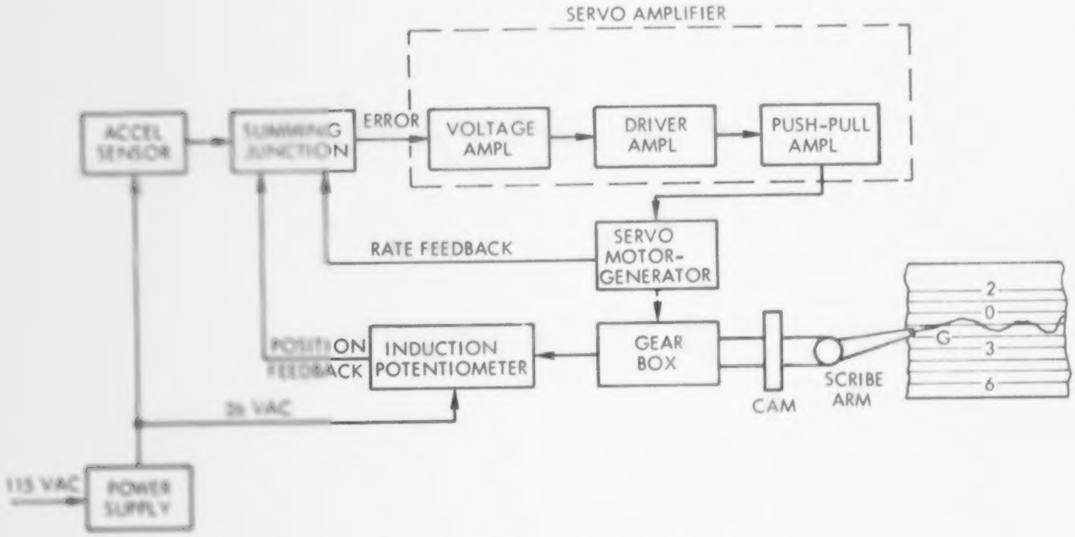


Figure 3-2. Vertical acceleration channel.

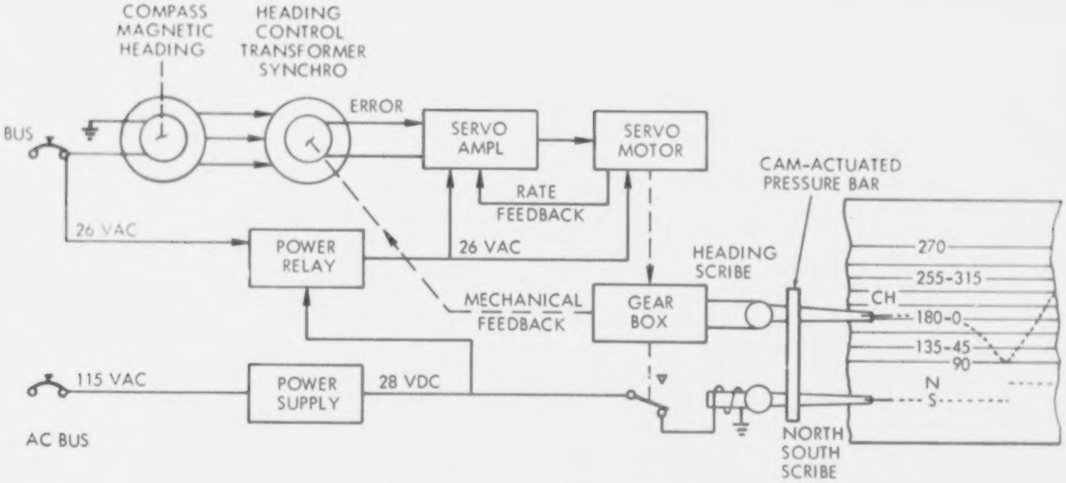

COMPASS MAGNETIC HEADING
HEADING CONTROL TRANSFORMER SYNCHRO
BUS
ERROR
SERVO AMPL
SERVO MOTOR
CAM-ACTUATED PRESSURE BAR
RATE FEEDBACK
26 VAC
POWER RELAY
26 VAC
HEADING SCRIBE
MECHANICAL FEEDBACK
GEAR BOX
270
255-315
CH
180-0
135-45
90
N
S
115 VAC
POWER SUPPLY
28 VDC
AC BUS
NORTH SOUTH SCRIBE

Figure 3-3. Compass heading channel.

Heading channel. The compass heading channel is shown in figure 3-3. It receives the magnetic heading synchro signal from the aircraft compass system. The signal is supplied to the stator of a control transformer synchro in the recorder. If the signal on the control transformer synchro is the same as the signal from the aircraft compass synchro, the servoloop is null and the servomotor will not drive. If the signals are not equal, an error signal will be produced on the rotor of the control transformer. The error signal is amplified and supplied to a servomotor. Following the flow arrows on figure 3-3, you will see that the servomotor drives, a mechanical feedback (gear train) positions the control transformer synchro rotor to null the error signal. At the same time, the heading scribe is positioned to indicate the magnetic heading of the aircraft.

A second scribe is controlled by a solenoid. It has two positions to indicate northerly or southerly headings. Notice in figure 3-3 that a mechanical linkage from the gearbox operates a switch that controls the electrical power to the solenoid of the north-south scribe. For headings between 90-180-270°, the switch closes and the solenoid positions the scribe to indicate southerly headings. For headings between 270-0-90°, the switch is open and the scribe records next to the letter "N" on the medium. Thus, the scribe indicates which heading scale values to read.

Altitude channel. The altitude channel, shown in figure 3-4, is all mechanical. The evacuated diaphragm is located in a sensing chamber inside the recorder. This sensing chamber is connected to the aircraft static pressure system. The diaphragm responds to changes in static pressure. Then, through a mechanical linkage, it directly positions the scribe to record the aircraft altitude. The range of the altitude channel is -1,000 feet to +50,000 feet.

Airspeed channel. Notice in figure 3-4 that the airspeed channel is similar to the altitude channel. The major difference is that the airspeed channel uses both pitot and static pressures. These pressures act on a diaphragm to position the scribe. The recording medium is calibrated between 0 to 450 knots indicated airspeed.

Exercises (827):

1. What controls the advancement rate of the recording medium in the flight data recorder system?

2. Which of the four channels recorded by the flight data recorder system is a continuous record not affected by the cam-actuated pressure bar?

3. How is north heading information distinguished from south heading information on the record medium?

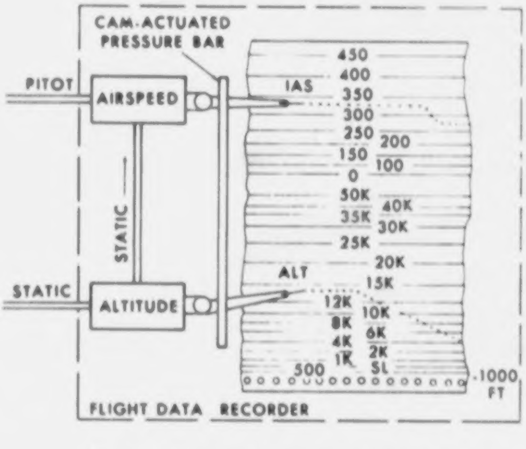

CAM-ACTUATED PRESSURE BAR
PITOT
AIRSPEED
IAS
450
400
350
300
250
200
150
100
0
50K
40K
35K
30K
25K
STATIC
20K
ALT
15K
STATIC
ALTITUDE
12K
10K
8K
6K
4K
2K
1K
SL
500
-1000 FT
FLIGHT DATA RECORDER

Figure 3-4. Airspeed and altitude channels.

4. When the output of the accelerometer is compared to the output of the induction potentiometer in the vertical acceleration channel of the flight data recorder, when is an error signal developed?

5. Refer to figure 3-3. Which components are mechanically driven?

6. What is the operational range of the altitude channel of the flight data recorder?

7. Explain the main difference between the altitude channel and airspeed channel of the flight data recorder system.

3-2. Aircraft Structural Integrity Monitoring systems.

The safety of an aircraft is dependent in part upon the strengths and weaknesses of the aircraft structure. Aircraft engineers have found that the stresses and strains imposed upon an aircraft during flight affect some parts of the airframe more than others. Early detection of such structural weaknesses is always desirable so that safe operating limits may be established. For this reason, the Aircraft Structural Integrity Program (ASIP) was established.

828. Identify ASIP components in terms of their functions.

ASIP. The Life History Recording System (LHRS) and the Flight Loads Data Recording system (FLDRS) are just two of the systems used to gather structural stress data in support of the ASIP. This program is an aid in predicting the life expectancy of the airframe for the purpose of establishing a safe fatigue life. This type of program is necessary because the vibrations and flexing of the aircraft and wings during flight tend to weaken the structural materials just as you can break a piece of wire by repeatedly bending it at the same point.

Various types of multichannel systems are used on various aircraft to record flight parameters related to structural loads. These flight parameters are recorded in a specific sequence on magnetic tape.

The system may receive event signals from such aircraft components as the aerial refueling receptacle door control, speed brakes, autopilot, landing gear ground safety switch relay, and entrance hatches (fig. 3-5). The flight parameters normally recorded include: pitch and yaw rate; rudder, elevator, and flap position, nose wheel steering; airspeed; altitude; vertical acceleration; pressurization; structural loads; taxi speed; strut compression; landing gear position; fuel load; and documentary data which is manually inserted into the recorder. The documentary data input is controlled by positioning digital thumbwheel selector switches on the front of the recorder. This documentary data consists of the aircraft serial number, gross weight, total fuel weight, configuration, and date. This information is recorded before and after each flight. Also included in the system is a built-in-test (BIT) circuit which verifies that the converter-multiplexer and the recorder are operating properly. The system uses 28 volts DC and 115 volts 400-Hz single-phase power. It begins to operate when the circuit breakers are closed, the ON-OFF switch is turned to ON, and when the record on switch is pressed momentarily.

Exercises (828):

1. Why is an aircraft structural integrity program necessary?

2. Name two systems of the ASIP.

3. List the flight parameters which may be monitored by ASIP units.

4. What kinds of documentary data must be manually inserted into the ASIP recorder?

829. Identify and state the purpose of controls, indicators, and other parts of an ASIP recorder unit.

Recorder. (fig. 3-6) The recorder is a 9-track unit capable of recording 240, 9-bit characters per second. This unit basically consists of four solid-state plug-in circuit boards (including a regulated power supply), power supply transformer, unregulated power supply, recorder drive assembly, 9-track write head assembly, documentary data encoder, power control relay, indicator lights, test and CAL deactivate switches, and a 10,000 hour digital readout elasped time indicator. A tape cartridge (used with the recorder) is installed through the upper hinged door on front of the unit. The door has a window through which the percent of tape remaining indicator is visible when the door is closed. The tape cartridge contains 1,200 feet of 1/2-inch magnetic tape, providing 15 hours of recording. Documentary data thumbwheel switches (24) are accessible through the lower hinged door. Four switches each are provided for airplane serial number, gross weight, and total fuel weight; two switches each are provided for base and mission; three for configuration; and five for date. Electrical receptacle J1, on front of the recorder, is provided for recorder checkout. The recorder uses power from the

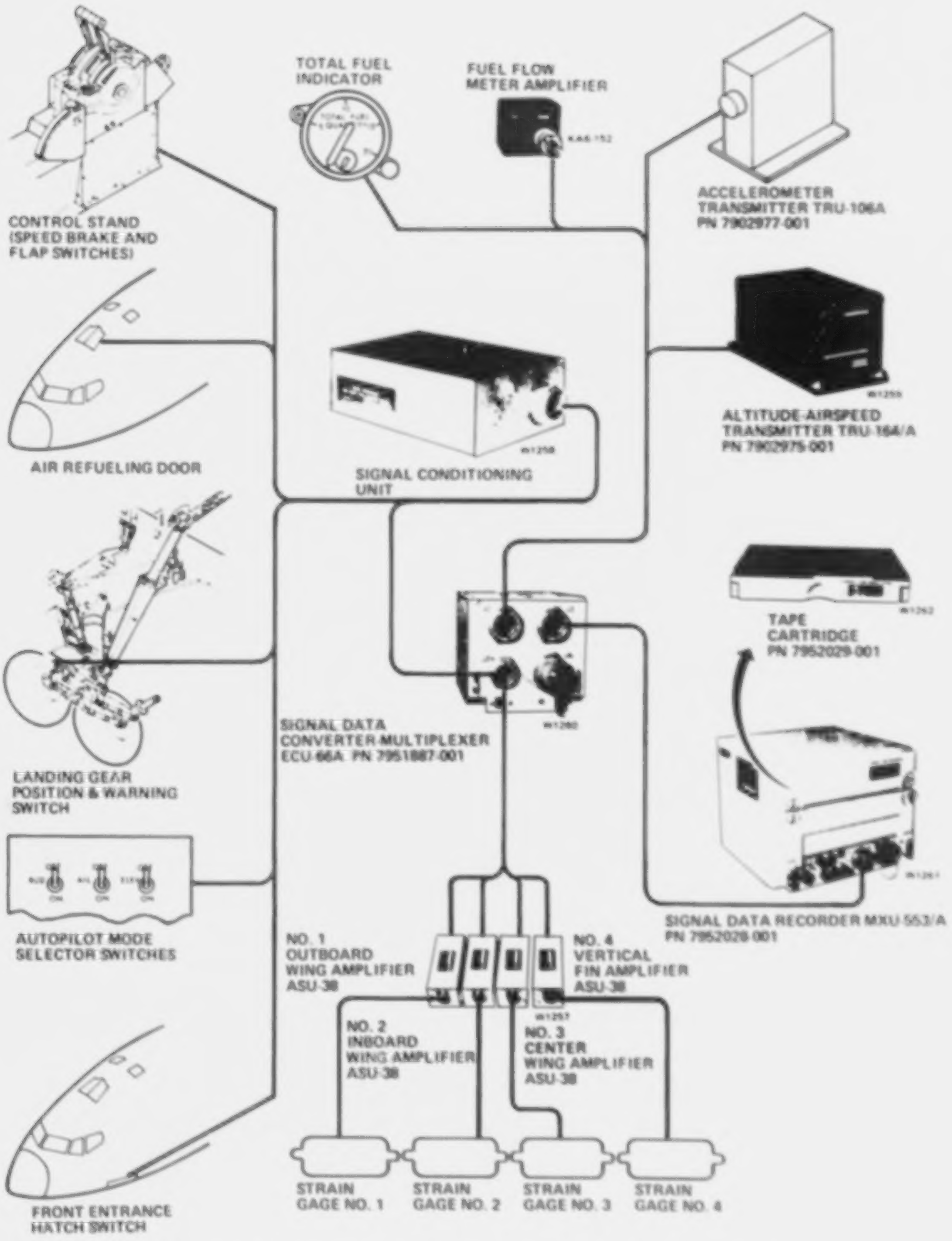

CONTROL STAND (SPEED BRAKE AND FLAP SWITCHES)
TOTAL FUEL INDICATOR
FUEL FLOW METER AMPLIFIER
ACCELEROMETER TRANSMITTER TRU-106A PN 7902977-001
AIR REFUELING DOOR
SIGNAL CONDITIONING UNIT
ALTITUDE-AIRSPEED TRANSMITTER TRU-164/A PN 7902975-001
TAPE CARTRIDGE PN 7952029-001
LANDING GEAR POSITION & WARNING SWITCH
SIGNAL DATA CONVERTER-MULTIPLEXER ECU-66A PN 7951887-001
SIGNAL DATA RECORDER MXU-553/A PN 7952028-001
AUTOPILOT MODE SELECTOR SWITCHES
ON
ON
ON
NO. 1 OUTBOARD WING AMPLIFIER ASU-38
NO. 4 VERTICAL FIN AMPLIFIER ASU-38
NO. 2 INBOARD WING AMPLIFIER ASU-38
NO. 3 CENTER WING AMPLIFIER ASU-38
FRONT ENTRANCE HATCH SWITCH
STRAIN GAGE NO. 1
STRAIN GAGE NO. 2
STRAIN GAGE NO. 3
STRAIN GAGE NO. 4

Figure 3-5. An Aircraft Structural Integrity Program system (Flight Loads Data Recording System)

airplane 28-volt DC bus and the 115-volt 400-Hz single phase bus.

Controls and indicators. The following list identifies the various system controls and indicators located on the recorder and describes their operation. All of these system controls and indicators are located on the recorder.

a. Elapsed Time Meter. Meter operates only when power is on and indicates elapsed hours of operation.

b. REC Failure Light. Light comes on when recorder has failed BIT test. If end-of-tape condition exists during BIT test, light flashes for 30 seconds and then stays on. Light flashes continuously when tape cartridge is at end-of-tape in normal operation.

c. SUP Data Light. Light comes on when documentary data switches have failed BIT routine.

d. MUX Failure Light. Light comes on when converter-multiplexer has failed BIT routine.

e. Test Pushbutton. Pressing TEST pushbutton initiates (built-in-test) BIT routine. If system power is off, BIT routine will turn system on for test.

f. Test Light. Light comes on during BIT routine and then goes off at conclusion. When system is operating, TEST light will remain on for approximately 10 seconds, then go out. When system is off, TEST light will be on for 45 seconds and then go out.

g. CAL Deactivate Switch. With switch in down position, three calibrated input levels of 10 percent, 50 percent, and 90 percent of full scale are recorded on tape once every three minutes of operation. With switch in up position, no calibration levels are entered on tape.

h. Documentary Data Thumbwheel Switches. Thumbwheel switches enter various static parameters pertaining to the airplane.

i. Tape Cartridge Access Door Interlock Switch Fastener. Fastener prevents operation of system unless access door is closed and locked.

j. Tape Cartridge Release Lever. Release lever releases tape cartridge when depressed downward.

k. Tape Remaining Indicator. Indicates by pointer, percentage of tape remaining. Total time is 15 hours.

Recorder tape cartridge. A removable recorder tape cartridge with a capacity to record 15 hours of data is contained within the recorder. This tape cartridge is removed when full and shippd to the data processing facility, Oklahoma City ALC/AIO, Tinker AFB OK 73145. To install or remove the tape cartridge open the upper hinge door of the recorder and depress the center spring lock. If too little tape remains for the flight, remove the existing cartridge and replace it with a full one.

Exercises (829):

1. What are the capabilities of the ASIP recorder?

2. What type of recording medium is used?

3. List the documentary data that must be manually inserted into an ASIP recorder.

4. What lights are located on an ASIP recorder?

5. What is the purpose of the tape cartridge access door?

6. How do you open the tape cartridge access door?

7. Describe the tape remaining indicator.

830. Identify LHRS component circuits with their functions.

System Normal Operation. Assuming power is applied to the LHRS and the recorder power control relay is energized, data from the sensor and airplane event circuits are applied to the converter-multiplexer. Information from the sensors is transmitted to the converter-multiplexer which conditions the signals and converts the data from an analog to digital form and then feeds the serial multiplexed data to the recorder. The input from each sensor is fed through a scaling circuit and then to the analog multiplexer. The scaling circuit conditions the signal to provide a common 0 to +5-volt range regardless of the normal range or polarity of the sensor signal. For example, the range of the pitch rate signal is 0 to +3 volts for nose-down rotation; 0 to −3 volts for nose-up rotation; and 0 volts in the static position. After scaling, the same signal is 2.5 to 5 volts for nose-down rotation; 2.5 to 0 volts for nose-up rotation; and 2.5 volts in the static condition. Low pass filtering is provided for all sensor signals except airspeed, altitude, ground speed, and pressurization before being applied to the analog multiplexer. The analog multiplexer sequentially (in turn) applies the sensor signals to the analog-to-digital converter where the signals are converted to an 8-bit plus parity binary word. Odd parity is used so that when any one of the input signals is zero, there will still be one pulse in the word. The output of the analog-to-digital converter is applied to the digital multiplexer. The airplane event inputs to the converter-multiplexer are merely level shifted from 28-volts DC to 5-volts DC (logic "1") and then applied directly to the digital multiplexer where these signals are grouped with the sensor signals. The digital multiplexer sequentially applies parallel format binary data to the parallel-to-serial converter which, in turn, provides serial format data to the serial parity generator. The serial format data with serial parity added is applied to the recorder digital multiplexer on a signal transmission line (data input to the recorder).

In the recorder digital multiplexer, the documentary data is sequentially interlaced, in serial format, with the sensor and events input from the converter-multiplexer and applied to the serial-to-parallel format converter. In turn, 8-bit (plus parity) words are applied in parallel format to the recorder write head and the data is recorded at a rate of 240 words (one data frame) per second. The parameters recorded are repeated in the same sequence every second with the exception of the timing word and gap which alternately appear on the tape at the beginning of each 1-second period. The timing word provides the time reference identification of the data frame. The gap provides separation between every other data frame.

Exercises (830):

Match the LHR system component/circuits (column A) to their functions (column B). Some selections in column B may be used more than once and some may not be used at all.

Column A
Component/Circuit

_____ 1. Converter-multiplexer.
_____ 2. Scaling circuit.
_____ 3. Analog multiplexer.
_____ 4. Analog-to-digital converter.
_____ 5. Digital multiplexer.
_____ 6. Parallel-to-serial converter.
_____ 7. Signal transmission line.
_____ 8. Recorder write head.
_____ 9. Timing word.
_____ 10. Gap.

Column B
Function

a. Provides the time reference for data frame.
b. Records 240 words per second.
c. Changes data from an analog to digital form.
d. Ranks the input signals in a 0 to 5-volt range.
e. Feeds the serial multiplexed data to the recorder.
f. Filters sensor signals.
g. Applies the sensor signals to the analog-to-digital converter.
h. Combines airplane event inputs with the sensor signal.
i. Sequentially applies binary data to the parallel-to-serial converter.
j. Provides separation between data frames.
k. Applies 8-bit words to the write head.
l. Converts signals to an 8-bit plus parity binary word.
m. Shifts airplane event inputs from 28-volts DC to 5-volts DC.
n. Provides data to the serial parity generator.

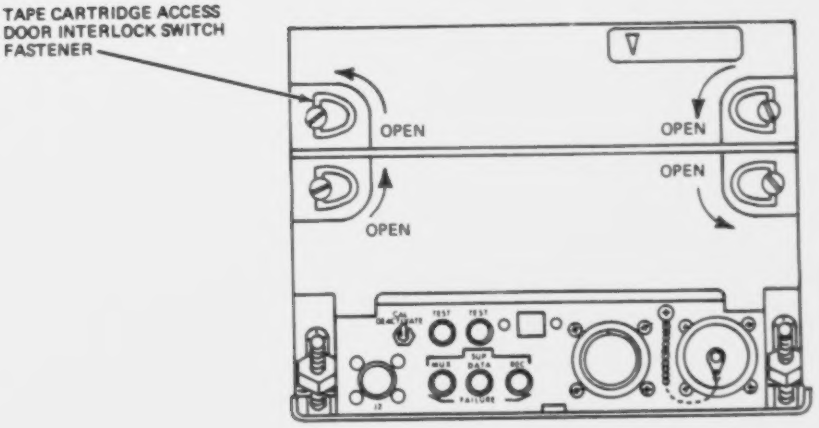
831. State how different segments of the recorder circuits are actuated.

Recorder Power Switching Circuits. When power is first applied to the Life History Recorder system (fig. 3-6), 28-volt DC from the aircraft bus is fed to the coil of a power control relay in the recorder, the TEST (BIT) switch, and the failure monitor lights.

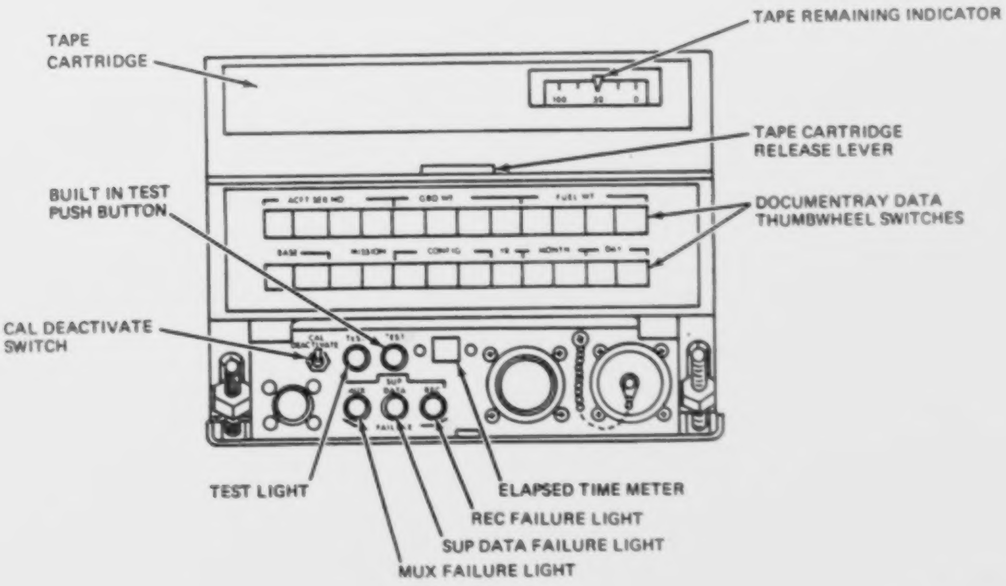
Switching transistors conduct to complete the ground circuit to energize a power control relay if a tape cartridge has been installed and the cartridge access door is closed (otherwise the relay will not energize). If the tape cartridge has not been installed, the ground circuit is completed for the REC failure light, turning this light on.

When the relay energizes, 28-volt DC is applied to the spool take-up and supply motors and to the spool engage solenoid. In turn, the solenoid energizes and pushes two pins into mating holes in the spindle of the take-up and supply spools. With the pins engaged in the spindles, the take-up and supply motors maintain tape tension. A switch in series with the solenoid power circuit opens after the solenoid energizes. At this point, the solenoid is held in by the series circuit through a 50-ohm resistor and the armature winding of the take-up and supply motors, keeping the solenoid energized with reduced current flow. The power return circuit for the motors, which are connected in series, is through the solenoid winding. With the power control relay energized, 115-volt AC is applied to the DC power supply which provides the various DC voltages required for system operation. 115-volt AC is applied also to the elapsed time indicators in the recorder and the converter-multiplexer, and they start operating. When the power supply is turned on, a master reset pulse is triggered to reset logic circuits, as required, and the time base generator in the converter-multiplexer generates the following timing pulses required for system operation: 7.68 KHz system clock, 3.84 KHz analog-to-digital converter clock, and a 240-Hz 2-phase write clock. The power supply provides 28-volt DC to the record motor driver which is switched by a 60 Hz, 2-phase clock developed in the recorder serial-to-parallel format converter. In turn, 60 Hz 2-phase power is applied to the record synchronous motor, and the motor starts operating. The tape is transported by capstans driven by the record motor. The tape is transported by capstans driven by the record motor. Thirty seconds after the power control relay energizes, the recorder starts recording data. At that time, and at 3-minute intervals thereafter, calibration data is recorded automatically for 3½ seconds for all channels at 10, 50, and 90 percent of full scale. This provides the necessary references for interpretation of the flight parameter data which is recorded continuously, except during the calibration periods. The CAL deactivate switch on the recorder remains in the up position to prevent calibration data from being recorded during flight. (See fig. 3-6).

Depressing the test button on the recorder also energizes the power control relay, since the two circuits are connected in parallel. However, in operation, the test button is only depressed momentarily and a paralleled circuit keeps the base of one of the switching transistors high during the test cycle. This circuit functions as follows: When the test button is depressed, that transistor conducts and in turn, a JK flip-flop in the BIT control circuit is set. This flip-flop and related logic circuitry provides a high output to the base of the other switching transistors, which continue conducting after the test button is released. In addition, the flip-flop enables the BIT circuit and provides a high output to the base of another transistor. In turn, it conducts and the test light comes on. At the conclusion of the test cycle, the flip-flop is reset, the power control relay de-energizes and the test light goes off. The signals used in BIT are 10, 50, and 90 percent of full scale, as used during calibration. The BIT cycle takes about 40 seconds. If there is a malfunction,


TAPE CARTRIDGE ACCESS DOOR INTERLOCK SWITCH FASTENER
OPEN
OPEN
OPEN
OPEN
CAL DEACTIVATE
TEST
TEST
SUP
MUX
DATA
REC
FAILURE

FRONT VIEW WITH DOORS CLOSED


TAPE REMAINING INDICATOR
TAPE CARTRIDGE
100
50
0
TAPE CARTRIDGE RELEASE LEVER
BUILT IN TEST PUSH BUTTON
DOCUMENTRAY DATA THUMBWHEEL SWITCHES
CAL DEACTIVATE SWITCH
TEST LIGHT
ELAPSED TIME METER
REC FAILURE LIGHT
SUP DATA FAILURE LIGHT
MUX FAILURE LIGHT

FRONT VIEW WITH DOORS OPEN

Figure 3-6. An ASIP recorder.

the applicable warning light on the recorder comes on in about 20 seconds. The warning lights indicate component failure as follows: If the converter-multiplexer has failed, the MUX failure light comes on. If the tape in the cartridge has been used up, the REC failure light blinks for approximately 20 seconds and then remains on.

Exercises (831):

1. What is the power source for the LHRS BIT switch?

2. Name two things that will prevent the recorder from operating.

3. How is AC power applied to the power supply?

4. How are the logic circuits automatically reset?

5. What is the power requirement for the record motor?

6. How long does it take for the recorder to start operating after power has been applied?

7. Why must the CAL deactivate switch be in the UP position during flight?

8. Depressing the test button applies power to the recorder circuits. How is that power removed after the test is completed?

9. How long does the BIT cycle last?

832. State how tape feed and use are monitored in the ASIP recorder.

Recorder Motion Sensor Circuit. The recorder motion sensor circuit senses the rate at which tape is transported from the supply spool to the take-up spool. This circuit uses a light source and a photocell mounted on opposite sides of a wheel driven by the take-up spool. Eighty equally-spaced holes are located around the outer edge of the wheel. The pulses generated by the photocell as the wheel turns, are applied to a counter circuit which determines tape speed. If a BIT is initiated (TEST button momentarily depressed) and the tape speed is not within specified limits, a transistor circuit starts to conduct (after about 20 seconds) and in turn, the REC failure light comes on.

Recorder End-of-Tape Sensor Circuit. The end-of-tape (EOT) sensor circuit uses two contacts which act as a switch to provide a ground (logic "o") to the EOT amplifier and logic circuit when the circuit across the contacts is closed. This circuit is closed when the tape on the supply spool is nearly exhausted. At that time, a metallic conductor, sprayed on the tape, completes the circuit across the two contacts and the EOT amplifier and logic circuits provide a pulsing output to a monitoring transistor which, in turn, alternately conducts and cuts off, causing the REC failure light to blink. At the same time, the motor clock input to the recorder motor driver is cut off, and the recorder drive motor stops. The motor driver circuit is essentially a 28-volt DC chopper circuit which is triggered by a 60-Hz signal.

Exercises (832):

1. How is the rate of tape movement sensed in the recorder?

2. What causes the REC failure light to illuminate steadily?

3. What causes the REC failure light to blink?

833. State the function of the ASIP converter-multiplexer.

Converter-multiplexer. The converter-multiplexer is a 26-channel unit which is capable of sampling input signals at 240 times per second. Seventeen channels handle analog (sensor) inputs and the remainder handle discrete inputs (airplane events). The converter-multiplexer is a hermetically sealed unit which basically consists of eight solid-state plug-in printed circuit boards and a 10,000-hour digital readout elapsed time indicator. The converter-multiplexer uses various DC voltages provided by the recorder power supply as well as airplane 115-volt 400-Hz single phase power which is switched through the recorder power control relay contacts. The 400-Hz power is used to operate the elapsed time indicator. Electrical receptacle J4 on front of the converter-multiplexer is provided for checkout.

Exercises (833):

1. How many channels does the converter-multiplexer have? It samples input signals at what rate?

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2. DC voltages are provided to it by ______________ ______________ ______________ ______________.

3. The converter-multiplexer uses 17 channels to process ______________ inputs and the remaining channels to process ______________ inputs.

834. Identify signal sensing units and their circuitry with their functions.

Airspeed and Altitude Transducer. The airspeed and altitude transducer (shown in fig. 3-7) provides electrical analog signals in response to airspeed and altitude parameters. The transducer is a hermetically sealed solid-state unit which uses power from the airplane 28-volt DC bus. This unit basically consists of an electronics module (printed circuit board), two sensors, a filter module, and an elapsed time indicator. The electronics module includes preregulator, DC to DC converter, constant current regulator, and amplifier circuits. Each semiconductor sensor consists of a single crystal pressure capsule with an integral diaphragm of N-type silicon with P-type diffused into the diaphragm. The sensors are wired to form a wheatstone bridge. Bridge resistance changes with changes in pressure and in turn, a signal results which is proportional to the pressure change. The operating range of the transducer is 0 to 800 knots for airspeed and -1,000 to 80,000 feet for altitude with an output of 0 to 5-volt DC for each sensor circuit. The elapsed time indicator, which is a 10,000 hour digital readout timer, is powered by the DC to DC converter.

Rate Gyro. The rate gyro is a hermetically sealed, three-axes (roll, pitch, and yaw) solid-state unit which uses power from the airplane 28-volt DC bus. However, only two axes are normally used—pitch and yaw. The unit basically consists of a voltage regulator, inverter, power supply, gyro and motor and gimbal assembly, a sensor and demodulator filter assembly for each axis, and an elapsed time indicator. The sensors are the inductive type called microsyns. Each sensor uses induction-coupled primary and secondary windings with a rotor varying the inductance. The rotor for each axis is mechanically positioned by the applicable gyro gimbal. The gimbals are torsion-spring restrained with gimbal movement limited by stops to +2° in each axis. The inverter is powered by 20-volt DC and the inverter switching circuits are controlled by 6-volt DC. Both sources of power are provided by the voltage regulator. In turn, the inverter output (26 volts, 800 Hz) provides excitation voltage to the sensors and power to the 2-phase gyro motor and to a power supply. The power supply provides +10 volts for the demodulator/filter assemblies. The signal from each sensor is applied to the corresponding demodulator/filter assembly through secondary windings of the inverter output transformer. The output of the demodulator/filter assemblies is 0 to +5 volts or 0 to -5 volts, depending upon the rate and direction of gyro rotation. The operating ranges of the rate gyro are 0 to +230° per second in roll, 0 to +70° per second in pitch, and 0 to +60° per second in yaw. The rate gyro, too, has an elapsed time indicator, which is a 10,000 hour digital readout timer, is powered by 26-volt DC provided by the voltage regulator.

Vertical Accelerometer. The vertical accelerometer (fig. 3-7) senses accelerations along the vertical axis only. The accelerometer is a hermetically sealed solid-state unit which uses power from the airplane 28-volt DC bus. The unit basically consists of a converter, a sensor, and demodulator/amplifier assembly. The sensor uses induction-coupled primary and secondary windings with a movable core varying the inductance. The accelerometer operates on the force-balance servoloop principle with the force developed by the inertia of a mass which tends to displace the core of the sensor. The output of the sensor is demodulated and amplified, providing a signal with a magnitude and polarity relative to the magnitude and direction of the G force. This signal is applied to a torquer in the sensor which acts on the mass in opposition to the G force, thereby maintaining the mass in a stationary position. The operating range of the vertical accelerometer is -1 to +4G, with an output of 1.25-volts to +5-volts DC.

Pressurization Transducer. The pressurization transducer is usually mounted on a rack located in the crew compartment area. The transducer is a thin film strain gage. The sensing element is vacuum deposited on a ceramic film covering the stainless steel beam-diaphragm. A full four element bridge is used. A force applied to the diaphragm causes a resistance unbalance in the bridge. A nominal 10-volt DC reference is applied across the bridge. The full scale output is 2 MV/V and the pressure operating range is +10 PSID.

Position Transducer. The control surface position transducers are located along the control cables for each flight-control surface. The nose wheel position transducer is usually located in the nose wheel well. The position transducers are unique sensing devices that translate a large mechanical movement or deflection into an accurate linear DC-voltage signal. The transducer uses an infinite resolution 1000-ohm potentiometer. Mechanically, these transducers are very simple. A cable clip is fastened to the moving surface and the transducer body is attached to a fixed surface. As the control surface moves in relationship to the transducer body, the cable is extended. This rotates the cable spool which in turn drives the potentiometer slider (wiper). When a voltage is applied across the potentiometer, a continuous signal is generated. The signal is proportional to the movement of the control surface. A constant force spring motor maintains cable tension during extension and provides the mechanical power to rewind the cable. The transducer is dust tight to prevent dirt from accumulating inside the transducer. The excitation voltage of the transducer is a 10-volt reference signal furnished by the converter-multiplexer. The rudder, elevator, and nose wheel transducers are centered in this 10-volt range at approximately +5 volts. The flap transducer output is approximately 9 volts when the flaps are full up.

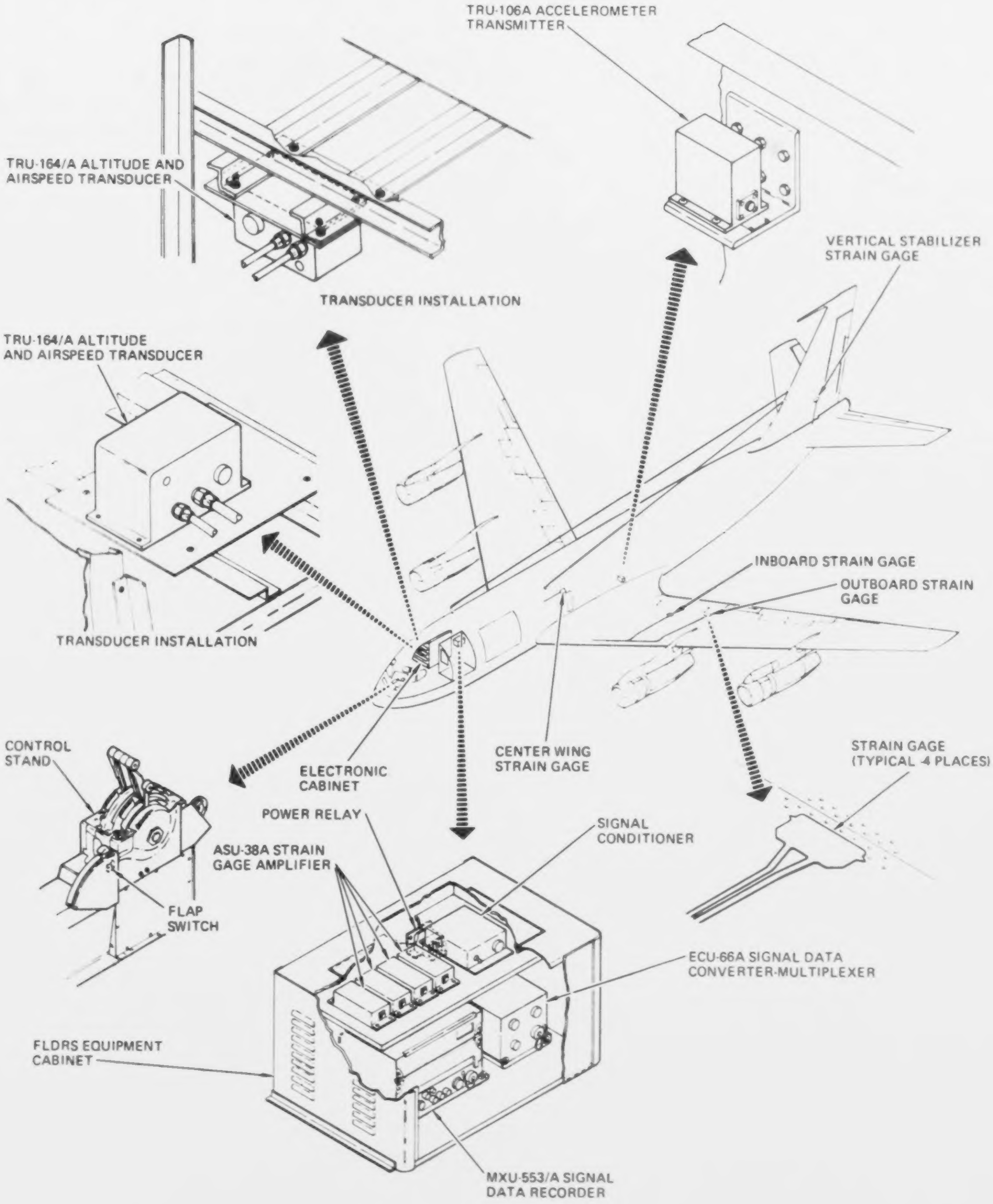
TRU-106A ACCELEROMETER TRANSMITTER
TRU-164/A ALTITUDE AND AIRSPEED TRANSDUCER
VERTICAL STABILIZER STRAIN GAGE
TRANSDUCER INSTALLATION
TRU-164/A ALTITUDE AND AIRSPEED TRANSDUCER
INBOARD STRAIN GAGE
OUTBOARD STRAIN GAGE
TRANSDUCER INSTALLATION
CONTROL STAND
ELECTRONIC CABINET
CENTER WING STRAIN GAGE
STRAIN GAGE (TYPICAL 4 PLACES)
POWER RELAY
SIGNAL CONDITIONER
ASU-38A STRAIN GAGE AMPLIFIER
FLAP SWITCH
ECU-66A SIGNAL DATA CONVERTER-MULTIPLEXER
FLDRS EQUIPMENT CABINET
MXU-553/A SIGNAL DATA RECORDER

Figure 3-7. Another ASIP system (Life History Recording system).

Pulse Rate Integrator. The pulse rate integrator is a sealed solid-state device powered by the aircraft 28-volt DC bus. The unit converts an antiskid tachometer generated frequency into a DC voltage for use by the converter-multiplexer. The frequency of the antiskid tachometer generator is a function of taxi speed. It was estimated by assuming that the rolling radius of the main landing gear tire is equal to the static radius. The 50-pulse generator used on large aircraft gives us about 7.3 Hz per knot of taxi speed for a standard of 1455 Hz at 200 knots of taxi speed. The DC output of the pulse rate integrator then, is a function of signal frequency only. It is independent of voltage levels between 10-millivolts and 50-volts rms. There is a trimpot adjustment for obtaining an input signal ratio of two to one for full scale. The full scale output is 5-volts DC.

Exercise (834):

1. Match the Aircraft Structural Integrity Program signal sensing units and their associated circuitry (column A) with their functions given in column B. Some selections may be used more than once and some may not be used at all.

Column A

_____ (1) Airspeed and altitude transducer.
_____ (2) Position transducer.
_____ (3) Elapsed time indicator.
_____ (4) Pulse rate integrator.
_____ (5) DC to DC converter.
_____ (6) Vertical accelerometer.
_____ (7) Torsion-springs.
_____ (8) Rate gyro.
_____ (9) Mass displaced core.
_____ (10) Pressurization transducer.
_____ (11) Cable spool.
_____ (12) Electronics module.

Column B

a. Centered in a 10-volt range.
b. Drives the wiper of a potentiometer.
c. Attached to a cable clip.
d. Translates a large mechanical movement into a linear DC voltage.
e. Uses a full four element bridge.
f. Consist of a converter, a sensor, and a demodulator/amplifier assembly.
g. Controls inductance in primary and secondary windings.
h. Contains two sensors.
i. Powers an elapsed time indicator.
k. Sensors form a wheatstone bridge.
l. Is a single crystal pressure capsule.
m. Converts a tachometer generated frequency into a DC voltage.
n. Output is a function of signal frequency.
o. 10,000 hour digital readout.
p. Restrain rate gyro gimbals.
q. Has inductive sensors called microsyns.
r. Includes preregulator, DC to DC converter, constant current regulator, and amplifier circuits.

835. State how strain gages and strain gage amplifiers operate.

Stain Gages and Strain Gage Amplifiers (Figs. 3-5 and 3-7). The strain gage bridge completion resistors and the strain gage amplifiers are usually mounted close to the recorder and the converter-multiplexer. The bridge consists of a temperature compensator and an active strain gage (measuring device only, not an indicator) located at the monitored structural area and two 350-ohm bridge completion resistors. Strain gages are located in critical areas of the fuselage and wings. Each strain gage has a spare gage connecting cable for future use in case the active strain gage malfunctions. The active leg of the bridge circuit is bonded to the monitored structure. The temperature compensated leg is bonded to a plate which is attached to the structure with a pliable adhesive. The bridge measures axial stress at the selected locations. In other words, it measures stresses and strains caused by movement of the aircraft about the horizontal, longitudinal, and vertical axes. A strain gage amplifier is provided for each strain gage. The bridge is balanced in the amplifier. The strain gage bridge circuit is excited by 9.5-volts DC through the ACTE/BRDG switch in the strain gage amplifier. The strain gage sends a signal to the amplifier when current flows through the bridge network caused by wing stress at the strain gage location. The strain gage amplifier receives the signal from the strain gage and amplifies it in two stages before it is sent to the multiplexer.

The strain gage amplifier is a hermetically sealed solid-state unit which uses 115 volts, 400-Hz single-phase power. The amplifier provides gains of 25, 50, 125, 250, and 500. Excitation for the bridge circuit is 10-volts DC from the converter-multiplexer. The output of the strain gage amplifier is 0 to 5 volts. The amplifier has a DC offset which is used to change the operating point at which zero (0) strain is measured. As an example, when the strain to be measured has the same magnitude of compression and tension strain, the offset is adjusted to 2.5 volts and the gain is adjusted so full scale will be equal to a change of 2.5 volts. Compressive strain is measured on the low end of the scale from 0 to 2.5 volts and tension strain is measured with an output on the high side of the scale from 2.5 to 5 volts.

The ACTE/BRDG switch on the front of the amplifier is positioned to BRDG during calibration, which is required when a new strain gage is installed or the system is reconfigured. Normal flight position of the switch is ACTE position. In the ACTE position, the strain gage is excited by 9.5-volts DC from the converter-multiplexer power supply.

Exercises (835):

1. List the components of the strain gage bridge circuit.

2. Where is the active leg of the bridge circuit located?

3. What do the strain gages measure?

4. Where is the bridge circuit balanced?

5. The strain gage signal is amplified in how many stages?

6. What is the source of the excitation voltage for the strain gage bridge circuit?

7. What is the voltage output of a strain gage amplifier?

8. List the types of strain measured for each end of the 0 to 5-volt range of the strain gage amplifier.

836. Identify steps used to operationally check ASIP subsystem components.

Operational Check. An operational check of the Life History Recorder or Flight Loads Data Recorder and their signal data converter-multiplexers is performed by the built-in-test (BIT) routine. Transducer, accelerometer, system events, total fuel quantity, and strain gage checks are independent procedures. Each check may be used as an after-installation check or as an operational check.

Recorder/converter-multiplexer-checkout. The operational checkout of the recorder should be done by the responsible technician/flight crewmember after dialing in the pertinent data. Check that the applicable circuit breakers are pushed in. Insure that the tape cartridge is installed properly by firmly pressing the left and right hand corners of the cartridge. Close both doors on the recorder and latch them securely. The recorder will not operate unless the tape cartridge door is closed, actuating a built-in switch.

Check that the CAL deactivate switch on the recorder is up (deactivated) and that all circuit breakers on the recorder circuit breaker panel are pushed in. Position power on-off switch to ON, and momentarily press record on switch to the UP position until record on light remains illuminated.

Press the TEST, MUX, SUP DATA and REC lights on front of recorder. Each light should come on while depressed. This is just to check the light bulbs.

Momentarily depress the built-in-test button on the recorder. The red test light will come on and remain on during the BIT for approximately 20 seconds. If the MUX, SUP DATA and/or REC light should come on and remain on, a malfunction exists. The failure lights indicate component failure.

Airspeed and altitude transducer checkout. This procedure requires power on the aircraft and the use of the TTU-205 test set. As mentioned in our discussion of EPR systems (Volume 4), always keep the TTU-205 in a horizontal position on a level surface (10°) and go through the warmup procedure before you connect the tester to the system or equipment to be checked.

Connect the hoses from the test set to the transducer static and pitot ports. Disconnect the electrical plug from the signal input connector (J1) on the converter-multiplexer. Connect your voltmeter between the pins of the aircraft wiring connector as specified in the technical order. Vary the altitude and airspeed output of the TTU-205 to obtain the test points which are also specified in the TO. Monitor your voltmeter for the voltages specified at each test point. The voltage indications should change smoothly and should agree with the altitude indications. At the completion of the check, perform the shutdown procedures for the TTU-205, disconnect it from the transducer, and reconnect the transducer into the system.

Accelerometer checkout. The accelerometer must be removed from its mount before it can be turned to check its output. Also, like the airspeed and altitude transducers, you check the accelerometer voltage output at the signal input connector of converter-multiplexer. You must refer to the applicable technical order to determine which pins in the connector carry the accelerometer signal. A digital voltmeter or multimeter will give you the accurate measurements required for checking this system as the output of this type of accelerometer is normally 1.25 volts at +1G. Get a helper at the accelerometer location to turn the accelerometer upside down. The output reading in this position should be a negative 1.25 volts, representing a negative G force. Next, position the accelerometer on its side so the sensing axis is parallel to the earth's surface. The digital multimeter should read 0.00 volts DC, representing zero "g"s. This check concludes your check of the accelerometer. If it checks good, reinstall it in the aircraft system. Otherwise, replace it. The system's events and position transducers can be checked in a similar manner.

Strain gage resistance check. Any time a strain gage is suspected to be defective, you will have to check its resistance. The only indications you will have of a strain gage failure will be a notice from the depot (the people who read the tapes) or an inability to adjust the amplifier. The strain gage check tests the resistance of the strain gage cables at the splice points before splicing or at the strain gage amplifier connector if the sensor has already been spliced into the system. The resistance at both points should be the same. The normal resistance values will be given in the TO.

Strain gage amplifier bridge balancing. The system must be operating for this task to be done. You have to accomplish the preliminary procedures given in the TO, such as closing the entrance hatches or installing jumper wires as necessary for your particular type of aircraft. Connect a DC digital voltmeter between the OUT or OUTPUT jack on the amplifier and aircraft ground. Set the ACTE/BRDG switch to ACTE. Adjust the NULL trimpot to zero (0) volts DC. Next, place the ACTE/BRDG switch to BRDG. Set the gain control as prescribed in the TO. It will usually vary for each aircraft station being monitored. Adjust the balance (BAL) potentiometer to obtain the required voltage output which is usually between 2.450 and 2.550 volts. Placing the ACTE/BRDG switch back to ACTE completes this check. Being able to balance the amplifier is usually a good indication that the amplifier and the strain gage are good.

Exercises (836):

1. How is the operational check of a signal data converter multiplexer performed?

2. Which operational checks on an ASIP system are independent procedures?

3. Why must the tape cartridge door be closed before an operational check can be performed?

4. Why does one press on the lights on the front of an ASIP recorder?

5. What is the purpose of each of the lights on the front of an ASIP recorder?

6. What test equipment do you need to operationally check an airspeed and altitude transducer?

7. What type of measurements do you make when operationally checking an airspeed and altitude transducer? At what location?

8. Why must an accelerometer be removed from its mount to perform an operational check?

9. Where do you connect your meter when checking a remote accelerometer used in a FLDS? What are you checking for?

10. Turning an accelerometer upside down will give an output equivalent to how many "g"s?

11. How do you check a strain gage?

12. When should you check a strain gage?

13. What preliminary procedures may be necessary before you can check the balance of a strain gage amplifier?

14. What type of meter should you use and how do you connect it into the system when nulling a strain gage amplifier?

15. What switch on the strain gage amplifier must you use during the balancing procedure?

837. Identify servicing requirements and ASIP system operational check procedures.

System Servicing and Operational Check. Normally, the instrument specialist will see that the recording system operates properly and that pertinent documentary data is manually dialed into the recorder at preflight. The instrument specialist will insure that the recorder tape cartridge is replaced when used up and that it is shipped to the data processing facility.

The system will perform its design function if the following procedures are carefully followed for each flight.

During the preflight of the aircraft, the specialist should check the recorder for adequate tape remaining to cover the forthcoming flight. The tape remaining may be read directly from the recorder tape cartridge in percent (fig. 3-8). Since the tape cartridge can record 15 hours of data, the hours remaining may be easily determined. In the example shown in figure 3-8, the reading indicates that 50% of the tape is remaining (7.5 hours). If you find that there is not enough tape remaining for the next flight, remove that cartridge and replace it with a fresh one by opening the upper door and depressing the center spring lock. If the aircraft will not be returning to its home base before the installed cartridge has been used up, insure that the flight crew is provided with enough extra cartridges to cover the entire mission.

Immediately return the used cartridge to the data processing facility. The address to which it should be mailed is given in the aircraft TO. Each tape cartridge is shipped to you packaged individually in a reusable container that is designed to protect the tape cartridge from damage in transit and from possible magnetic exposure of the tape. Save the container for mailing the used tape back to depot.

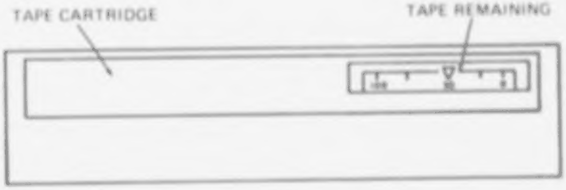

Figure 3-8. Cartridge tape-remaining indicator.

During the operational checkout after cartridge replacement, the specialist will dial the pertinent documentary data into the recorder. The following data for takeoff configuration is required.

1. Aircraft Serial Number—Four digits are provided. Dial in the last four digits of the aircraft serial number using ACFT SER NO dials. This data should not be changed.
2. Aircraft Gross Weight—Four digits are provided. When gross weight is 100,000 pounds or greater dial in the first four digits of gross weight. This data is easily obtainable from weight and balance form (DD Form 365F).
3. Fuel Weight—Four digits are provided. Dial in fuel weight in the same manner as aircraft gross weight using FUEL WT dials. The first digit will be zero if fuel weight is less than 100,000 pounds. This data is also obtained from the weight and balance form.
4. Base of Assignment—Two digits are provided. Dial in applicable base of assignment as listed in the TO using BASE dials. Base of Assignment will be defined as home base. This input should not change unless the aircraft is on extended temporary duty planned for 15 days or more at another base. If this occurs, dial in the new base.
5. Mission—Two digits are provided for mission. Dial in the applicable mission type as listed in the TO using MISSION dials.
6. Configuration—Three digits are provided for configuration. Dial in the configuration using CONFIG dials. Dial in applicable configuration code as listed in the TO.
7. Date—YR, MONTH, DAY: One, two, and three digits are provided for year, month, and day respectively. Dial in the *zulu* date on which the flight takes place using YR, MONTH, and DAY dials. For single digits on month and day, precede the number with a zero.

After dialing in pertinent documentary data, perform an operational system check, as follows:

1. Insure that the tape cartridge is installed properly by firmly pressing the left and right-hand corners of the cartridge. Insure the remaining tape is adequate for the flight.
2. Insure all pertinent data has been dialed into recorder.
3. Close both doors on recorder and latch securely. Tape cartridge door must be closed and latched or recorder will not operate because of a built-in switch that is closed by the upper door. (NOTE: CAL DEACTIVATE switch on the recorder should remain in DEACTIVATE (UP) position at all times).
4. Insure that ASIP RECORDER 28-volt DC and 115-volt AC circuit breakers on the main circuit breaker panel are closed.
5. Connect external electrical power to the aircraft.
6. Close the latch front entrance hatch and cargo door if necessary. DOOR WARNING light on copilot's instrument panel should go out.
7. Press TEST, MUX, SUP DATA, and REC lights for light bulb check.
8. Press TEST button, TEST light should come on for approximately 45 seconds, then go out. MUX, SUP DATA, and REC lights should remain out. If any failure lights come on, troubleshoot.
9. When testing is complete, insure that the ACTE/BRDG switch on each amplifier is in the ACTE position.
10. Open front entrance hatch and cargo door. Recorder should stop operating and door warning light on copilot's instrument panel should come on if the aircraft is so configured.
11. Open 28-volt DC ASIP RECORDER and 115-volt AC ASIP RECORDER circuit breakers.
12. Disconnect external electrical power from the aircraft.

Exercises (837):

1. List four duties relating to the Aircraft Structural Integrity program that are normally assigned to instrument specialist.

2. When an ASIP system is installed on an aircraft, what must be checked before every flight?

3. What type of documentary data that is manually inserted into the ASIP recorder is for aircraft configuration?

838. Identify hypothetical troubles in an ASIP system with their probable cause and state the trouble isolation procedure for each trouble given.

Trouble Analysis. The built-in-test (BIT) capability of the system will isolate most recorder or converter-multiplexer system malfunctions. Replace the faulty component as indicated by indicator lights on the recorder. Incorrect input data may be detected by analysis of tape from a previous flight. Data flow, event circuits and electrical control diagrams should be used with flight tape analysis and troubleshooting tables, such as table 3-1, to troubleshoot the system. If the probable causes listed in the tables do not isolate the trouble, check continuity of the system wiring. If a circuit breaker opens after closing, do not close it again until the trouble is found and corrected.

Exercises (838):

1. How do you check an ASIP recorder or converter-multiplexer?

2. When checking an ASIP recorder on the aircraft, what indicates a defective component?

TABLE 3-1
RECORDER/CONVERTER—MULTIPLEXER—TROUBLE ANALYSIS

TROUBLE	PROBABLE CAUSE	ISOLATION PROCEDURE	REMEDY
TEST light fails to come on when TEST pushbutton is pressed	Recorder defective		Replace recorder
	Airplane power not applied to recorder	Check that the RECORDER circuit breakers are closed	Close circuit breakers
		Disconnect the power input plug from the recorder and check for 115 (±15) volts ac and for 28 volts dc	If voltage is present, check interlock circuit
			If voltages are not present, check electrical distribution
REC FAILURE light comes on as result of BIT test	End-of-tape condition exists	Watch the REC FAILURE light. It flashes for 30 seconds and then stays on	Replace with new tape cartridge
	Tape cartridge defective		Replace tape cartridge and repeat BIT test
	Recorder defective		Replace recorder
MUX FAILURE light comes on as result of BIT test	Converter-multiplexer defective		Replace converter-multiplexer and repeat BIT test
SUP FAILURE light comes on as a result of BIT test	Recorder defective		Replace recorder and repeat BIT test
Multiple FAILURE lights (REC, MUX, SUP) come on as a result of BIT test	Converter-multiplexer		Replace converter-multiplexer
	Recorder defective		Replace recorder
No digital output on recorder for total fuel quantity gage		Perform total fuel quantity checkout	
		If correct results are not obtained	Replace indicator
		If voltage checks	Replace converter-multiplexer
No digital output on recorder from strain gage amplifier(s)	Converter-multiplexer defective	Perform strain gage amplifier balancing	
		If correct results are obtained	Replace converter-multiplexer
	Strain gage amplifier defective	If correct results are not obtained then check strain gage resistance	
		If resistance is correct	Replace strain gage amplifier
		Check for 115 volts ac at the electrical plug disconnected from amplifier	
		If voltage checks	Replace strain amplifier
No digital output from transducer	Transducer or converter-multiplexer defective	Perform transducer checkout	
		If correct results are obtained	Replace converter-multiplexer
		If correct results are not obtained when performing transducer checkout	Replace transducer

TABLE 3-1
RECORDER/CONVERTER – MULTIPLEXER – TROUBLE ANALYSIS (CONT)

TROUBLE	PROBABLE CAUSE	ISOLATION PROCEDURE	REMEDY
No digital output on recorder from axial accelerometer	Accelerometer or converter-multiplexer defective	Perform axial accelerometer checkout	
		If correct results are obtained	Replace converter multiplexer
		If correct results are not obtained then check 28 volts dc	
		If voltage checks	Replace accelerometer

3. What should you do if a circuit breaker opens again after you close it?

4. What indication would you get if the input data to an ASIP recorder was incorrect?

5. Match the probable corrective action, column B, to each of the hypothetical troubles listed in column A. Some of the selections in column B may be used more than once and others may not be used at all.

Column A

_____ (1) No digital output from a transducer.
_____ (2) SUP FAILURE Light comes on as a result of BIT test.
_____ (3) TEST light fails to come on when TEST button is depressed.
_____ (4) REC FAILURE light comes on as result of BIT test after installation of a new tape.
_____ (5) No digital output on recorder from strain gage amplifier but the amplifier balances.

Column B

a. Remove and reinsert tape and repeat BIT test.
b. Replace converter-multiplexer.
c. Replace strain gage.
d. Replace strain gage amplifier.
e. Replace light bulb.
f. Reset circuit breaker.
g. Replace recorder.
h. Replace transducer.
i. Replace tape cartridge.
j. Reseat tape cartridge.

839. Identify normal maintenance requirements and procedures in maintaining an ASIP system.

System Maintenance. Maintenance of systems used in the Aircraft Structural Integrity program consists of replacement of defective components, adjustment of strain gage amplifiers, repair or replacement of defective airplane wiring and connection of spare strain gage cables. Replacement of the strain gages is not a flight line procedure. Procedures for replacing recorder, converter-multiplexer, altitude and airspeed transducer, accelerometer, and strain gage amplifiers are obvious and can be done with hand tools. The following paragraphs contain procedures for connecting the spare strain gage cable and adjusting the strain gage amplifier. Always check the resistance of the spare strain gage before you use it. If the correct resistance values are not obtained, it should be considered inoperative and not used. If the spare strain gage is good, cut the defective gage out of the system at the splice point. Mate the spare strain gage leads as shown in the applicable TO and solder each strain gage lead to its corresponding lead in the aircraft wiring. Check the strain gage resistance at the electrical plug removed from the applicable amplifier to make sure your splices are good. Replacing a complete strain gage is depot type maintenance only and will not be attempted in the field.

Removal and replacement. Removing and installing the components used in these systems has been made as simple as possible. The recorder and the converter-multiplexer simply slide into a mount where they are held secure by two nut-type clamping fasteners. The electrical connectors just snap on their mating receptacles. One thing to remember about the recorder installation; the CAL DEACTIVATE must always be kept in the DEACTIVATE position for normal operation. Replacement procedures for pitot and static pressure operated components will be covered later in this course. The strain gage amplifiers, rate gyro, and the accelerometer are mounted with four screws and self-locking nuts. Anytime a new amplifier is installed, it must be balanced. The rate gyro and the vertical accelerometer must be installed facing toward the front of the aircraft. The position transducers are also mounted with screws and nuts. Be careful not to let the transducer cable snap back or it will damage the transducer. Follow the TO instructions for adjusting cable extension and securing the cable. The pulse rate integrator also requires adjustment after installation. This procedure requires that you use an oscillator, a digital multimeter, and a frequency counter to apply a precision 1455-Hz 0.1-volt signal through the input connector. The trimpot on the pulse rate integrator must be adjusted until the digital multimeter indicates 5 volts DC. Decreasing the input frequency to 727 Hz and then to zero (0) Hz should give you readings of 2.5 volts DC and 0.0 volts respectively.

Shutdown criteria. During operational checkout and testing, failure of recorder, multiplexer, or airspeed-altitude transducer will require complete system shutdown. The system will remain shutdown until the failed item(s) has been replaced. If other components fail, the recorder will continue to operate.

Exercises (839):

1. List the normal ASIP maintenance actions that can be accomplished on the flight line by using common hand tools.

2. What component in an ASIP system must normally be replaced at a depot facility?

3. If it is necessary to use the spare strain gage, how many times should you measure the resistance of that strain gage? Explain your answer.

4. Which component(s) of an ASIP system must face the front of the aircraft for proper operation?

5. What caution should you exercise when replacing a position transducer in an ASIP system?

6. To adjust which component of an ASIP system do you need oscillator and a frequency counter?

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NOTE: None of the items listed in the bibliography are available through ECI. If you cannot borrow them from local sources, such as your base library or local library, you may request one item at a time on a loan basis from the AU Library, Maxwell AFB AL 36112, ATTN: ECI Bibliographic Assistant. However, the AU Library generally lends only *books* and a limited number of *AFMs*. TOs, classified publications, and other types of publications are *not* available. Refer to current indexes for the latest revisions of and changes to the official publications listed in the bibliography.

Answers for Exercises

CHAPTER 1

Reference:

800 - 1. A ratiometer type of movement.
800 - 2. A bellows.
800 - 3. A mechanical linkage.
800 - 4. Resistors R_1 and R_2 are current limiting resistors which control the magnetic field strength of coil C_1, thereby controlling the range of pointer movement.
800 - 5. The value of R_2.
800 - 6. The resistance strip makes up one leg of the bridge circuit. The two deflection coils form the other leg.
800 - 7. The pointer should be held at midscale by the scale length coil when no current is flowing across the bridge.
800 - 8. Coil 1 and coil 2.
800 - 9. Zero.
800 - 10. At the R+ end.
800 - 11. The current flow in coil 1 decreases and the current flow in coil 2 increases.
800 - 12. The strength of the magnetic field of the scale length coil.

801 - 1. The 0–1 Field tester.
801 - 2. An indicator and a tank unit.
801 - 3. When you turn the R+ or R– screws, you increase or decrease the resistance of the resistance strip.
801 - 4. The R– screw is adjusted for FULL and the R+ screw is adjusted for EMPTY.
801 - 5. The indicator will read off-scale (EMPTY).
801 - 6. Dust on the resistance strip.
801 - 7. Equalize the travel by pivoting the contact arm with your thumb or forefinger. After it is equal, loosen the link adjusting screw very slightly and increase or decrease the length of the contact arm until its travel is 0 to 90.
801 - 8. Use an ohmmeter or a multimeter.
801 - 9. Contact arm; link adjustment screw.
801 - 10. Decrease; increase.

802 - 1. It equals the voltage of its charging source.
802 - 2. The farad.
802 - 3. The surface area of the plates, the distance between the plates, and the material between the plates (dielectric).
802 - 4. The total capacitance of a number of capacitors connected in series equals the reciprocal of the sum of the reciprocals of the individual capacitances.
802 - 5. A tank unit, a bridge unit, an indicator, and an amplifier. The bridge unit and amplifier may be built into the indicator.
802 - 6. The bridge unit measures the capacitance of the tank unit.

803 - 1. The area of the plates and the distance between the plates.
803 - 2. The capacitance of the unit is compared to a known capacitance, using a capacitance bridge circuit.
803 - 3. Capacitive reactance decreases.
803 - 4. When removing fuel, the potential difference from P to K and the potential difference across the reference capacitor is in phase.
803 - 5. It energizes the variable-phase winding of the induction motor in the indicator.
803 - 6. The indicator's motor drives a potentiometer in the reference capacitor leg of the bridge circuit until the system is in balance (null).

804 - 1. The range adjustment in the bridge amplifier is made variable, thus varying the voltage output to the tank units so that the system can be used on various aircraft.
804 - 2. With a temperature change, the fuel level on the probe changes; but at the same time, the dielectric constant of the fuel changes, and the two counterbalance each other.
804 - 3. Fuel characteristics and density are counteracted by the compensator, which is kept completely immersed in fuel and is electrically connected into the reference capacitor leg of the bridge.
804 - 4. The compensator is located at the lowest possible usable level of fuel, so that it is completely immersed until the tank or tanks are nearly empty.
804 - 5. A tank unit with a compensator built into it would have three connectors.

805 - 1. A tank unit is basically a variable capacitor.
805 - 2. A noncharacterized tank unit.
805 - 3. A characterized tank unit is designed for fuel tanks of nonuniform shape. Plate areas are varied. The tank unit is tailored to match the tank so that you get a uniform capacitance throughout the full length of the tank unit.
805 - 4. The flange-mounted and the internally mounted.
805 - 5. By installing two or more tank units in the tank.

806 - 1. Simulators can be used to simulate empty capacitance when drop tanks are jettisoned or removed. They can also be used in a selective indicating system, e.g., for indicating feed tank fuel level.
806 - 2. The simulator is set to empty capacitance of the tank.
806 - 3. DC relay, variable and fixed capacitors.
806 - 4. They are at ground potential.

807 - 1. Since the capacitance fuel quantity system operates at the null point, any variations in power are felt in the entire system; therefore, no change takes place in the indications.
807 - 2. The voltage signal originates in the bridge unit between points K and P (fig. 1-12).
807 - 3. Base current.
807 - 4. The right plate of the discriminator is positive and conducts.
807 - 5. Discriminator current is in phase with line current.
807 - 6. The selenium rectifier and filter network.
807 - 7. The current-limiting resistors in the bridge amplifier protect the transformer from short circuits.
807 - 8. The test switch closes a circuit to reduce voltage to the tank units. This action greatly unbalances the bridge circuit and drives the indicator toward zero. When the test switch is released, the bridge is once again balanced, and the pointer returns to its original position if the system is operating normally.

808 - 1. The signal-sensing device in the indicator is the motor.
808 - 2. It produces, with the inductance of the winding, a circuit that is nearly series-resonant.

809 - 1. Coaxial cables transfer the electrical signals from the tank units and compensator with a minimum of loss, interference, or radiation.

809 - 2. The connectors used in the fuel-quantity indicating system are of a special quarter-turn, bayonet-locking type.

810 - 1. The compensator would be installed in the tank that is emptied last—the forward main tank.
812 - 2. The full and empty adjustments are made with two screws located on the back of the instrument.
810 - 3. On a cargo aircraft, only one compensator is required in a tank regardless of the number of tank units.
810 - 4. The scale range and the sizes of the resistors and capacitors in the bridge and amplifier circuits.
810 - 5. In parallel.

811 - 1. A quick operational check of the fuel-quantity indicating system can be made by applying the correct power to the system and allowing sufficient time for the components to warm up and for readings to stabilize. Record the readings of all indicators, including the totalizer, and press the push-to-test switch for the totalizer and individual indicators until they rotate 15 to 20 angular degrees counterclockwise. Release the push-to-test switch, and all the indicators must return to their original readings. The sum of the individual indicators' readings must agree with the totalizer reading within 1.0 percent.
811 - 2. The MD-1, TF20, or the GTF-6 capacitance fuel-quantity tester may be used.
811 - 3. Use the test set calibration chart.
811 - 4. Lead wire and connector repair or replacement; replacement of the desiccator; and cleaning the terminal pins, clips, and tee connectors.
811 - 5. The MD-2A tester is used to test tank units and cables while they are installed in the aircraft or in the shop.
811 - 6. Never short the megohmmeter leads together, do not measure resistance values below the range of the instrument, keep the megohmmeter range selector in the CAL position except when you are actually making insulation resistance checks, and do not check shorted tank units on a range higher than X1. The internal parts of the meter can be damaged if these precautions are not observed.

812 - 1. If the correct polarity is not observed indicator components can be damaged.
812 - 2. The indicator adjustment check determines whether indicator empty and full adjustments have been made properly.
812 - 3. A scale-error check.
812 - 4. The zero-signal check determines whether the bridge is electrically balanced with the pointer at rest.
812 - 5. The dead-spot check determines the lag between rotor movement and capacitance change.
812 - 6. The capacitance of the tank unit and compensator can be measured individually. When measuring the capacitance of either the tank unit or compensator, the unshielded lead and coaxial lead are used and the unused compensator lead should be grounded.

813 - 1. When there is an apparent malfunction in a tank unit, check the wiring first and then remove the tank unit and visually check it. If the tank unit is defective, remove it.
813 - 2. The preferred method and the alternate method.
813 - 3. The dry tank units and compensator provide the capacitance input to the system.
813 - 4. Only when it is impractical to drain the fuel tanks.
813 - 5. The most important thing to remember when troubleshooting a fuel-quantity system is to use the applicable TO for the system on which you are working.
813 - 6. Defective wiring.
813 - 7. From the low end of the scale to avoid errors caused by gear backlash.

814 - 1. All electrically operated instruments are normally bonded to provide a low resistance path to eliminate possible differences in potential. One exception to this rule is capacitance type fuel-quantity systems in which a single-point ground for the shield is critical.
814 - 2. To eliminate any possibility of electrical shock or inadvertently routing 115 volts into the fuel tank.
814 - 3. Nylon and other man-made materials build up static electrical charges which produce arcing when discharged; therefore, they must NOT BE WORN inside fuel tanks or when explosive vapors are present.
814 - 4. Two people are required to perform maintenance inside a fuel tank. One must remain immediately outside the tank opening to monitor the coherency and sobriety of the individual working in the tank, because fuel vapors are very toxic and intoxicating.
814 - 5. Coax connectors.

CHAPTER 2

815 - 1. The main electrical unit of the position transmitter is a circular resistance winding with taps spaced 120° apart.
815 - 2. Voltages vary with the position of the transmitter wipers causing current to flow in the indicator coils. This current flowing in the indicator coils creates a magnetic field within the indicator movement. The permanent magnet rotor aligns with the magnetic field of the coils.
815 - 3. Since tap 2 is located approximately 1/3 of the distance between the power contact arm and the ground contact arm, approximately 1/3 of the applied voltage will be dropped, in this case, 9 volts.
815 - 4. The indicator pointer would point toward coil 1.

816 - 1. Check that the position indicator and transmitter are mounted securely and are in good overall condition. Be sure the range markings are placed properly on the indicator.
816 - 2. Two people. One operates the flaps while the other acts as a safety observer outside the aircraft.
816 - 3. At full up and full down.

817 - 1. The pointer of the indicator will not move. If power fails while the system is in operation, the pointer will point to the off-scale position.
817 - 2. A multimeter.
817 - 3. The transmitter can be bench checked with a selsyn tester. The indicator can be bench checked with a mockup using a transmitter as the sending device.

818 - 1. When the landing gear is down and locked.
818 - 2. The cross-hatched warning symbol.
818 - 3. The dial of the landing gear position indicator is moved by the attraction of the magnetic fields of the electromagnet.

819 - 1. Be sure the components are mounted securely and are in good physical condition. Electrical wiring and connectors should also be checked for proper insulation, safetying, and tightness.
819 - 2. Manually open and hold the down switch open and manually close the up switch.
819 - 3. When you operationally check a landing gear position-indicating system, you should make sure that you actuate only the indicator switches on the landing gear that operate the indicating system.

820 - 1. (1) a, c, g, h.
(2) b, e, h.
(3) h, i.
(4) d, h.
(5) h.
(6) c, h, j.
(7) c, f, h.

821 - 1. Blood drains from the head and everything appears gray. If enough positive g's are pulled, a person will blackout.
821 - 2. Blood rushes to the head and it appears as though a red curtain is being pulled over your eyes.
821 - 3. Type of aircraft, duration of maneuver, gross weight, and structural strength of aircraft.

822 - 1. The accelerometer indicates acceleration action along the vertical axis of an aircraft.
822 - 2. They indicate the highest plus and minus readings reached during any flight maneuver.
822 - 3. The amount of movement of the auxiliary pointers depends upon the number of ratchet teeth that pass and are caught by the pawl as the main shaft turns.
822 - 4. In straight and level flight, the accelerometer will indicate +1g because the lift force is equal to the aircraft weight. Therefore,

the only force acting on the aircraft is the force of gravity.

822 - 5. Negative g-forces are experienced only when the aircraft is in a pullover maneuver.

823 - 1. The main and auxiliary pointers should read +1 g.

823 - 2. Lock the indicating mechanism.

824 - 1. The aircraft magnetic compass is a standby instrument for emergency use only. It provides a heading reference for use when the navigation system fails.

824 - 2. The card of the standby compass is read against a lubber line.

824 - 3. The card element in the standby compass floats in a compass fluid. It is graduated in 5° increments to represent horizontal angles. The cardinal (major) headings are indicated by N., S., E., and W. Also, each 30° is indicated by a number corresponding to the angle.

824 - 4. Two sets of permanent bar magnets that are adjusted by screws on the front of the instrument.

824 - 5. The standby magnetic compass is located in the cockpit in an area that is relatively free of magnetic interference. Normally, this is the upper center portion of the windshield.

824 - 6. Nonmagnetic (usually brass) tools must be used when installing or compensating the standby compass.

824 - 7. There must be no ferrous materials in the area around the compass.

824 - 8. Using a sight compass or reference to a recently swung remote compass system.

824 - 9. If a standby compass is painted red, it means that the magnets have been reversed and all indications are in error 180°. It must never be installed in an aircraft.

824 - 10. The minimum number of people required to ground swing a standby compass is three (two instrument specialists and a pilot to taxi the aircraft).

824 - 11. Don't carry any object containing ferrous metals.

824 - 12. After engine start when all systems normally used during flight are operating.

824 - 13. DD Form 1613.

824 - 14. If you must subtract from the compass reading to get the actual aircraft heading, the sign is minus (-). If you must add to the compass reading to get the actual heading, the plus (+) sign is used.

825 - 1. (1) Deviation errors at the four cardinal headings.

Cardinal Heading	*Master Compass*	*Aircraft Compass*	*Deviation*
N	355°	003°	-8°
E	091°	085°	+6°
S	183°	183°	0°
W	265°	271°	-6°

(2) Solved Coefficients

$$\text{Coeff A} = \frac{N + E + S + W}{4} = \frac{(-8) + (+7) + (0) + (-6)}{4} = \frac{-7}{4}$$

$= -1.75$ rounded off to the closest whole number $= -2$.

$$\text{Coeff B} = \frac{E - W}{2} = \frac{(+6) - (-6)}{2} = \frac{+12}{2} = +6$$

$$\text{Coeff C} = \frac{N - S}{2} = \frac{(-8) - (0)}{2} = \frac{-8}{2} = -4$$

(3) Minimum Deviation

After solving for Coefficients A, B, and C, correct the index or installation error as computed in Coefficient A. When you correct the index error, you change all of the other errors by the amount of the index error. So, now at the same actual aircraft headings you have.

Cardinal Heading	*Master Compass*	*Aircraft Compass*	*Deviation Is Now*
N	355°	003° + (-2°) = 001°	-6°
E	091°	085° + (-2°) = 083°	+8°
S	183°	183° + (-2°) = 181°	+2°
W	265°	271° + (-2°) = 269°	-4°

Because you did the same thing to each of the cardinal headings, the coefficients that you computed do not change.

When you apply Coeff C (-4°) to correct the errors on the North and South headings, you have:

Cardinal Heading	*Master Compass*	*Aircraft Compass*	*Deviation Is Now*
N	355°	001° + (-4°) = 257°	-2°
S	183°	181° - (-4°) = 185°	-2°

Then you apply Coeff B (+6°) to correct the errors on the East and West headings, you have

Cardinal Heading	*Master Compass*	*Aircraft Compass*	*Deviation Is Now*
E	091°	083° + (+6°) = 089°	+2°
W	265°	269° - (+6°) = 263°	+2°

825 - 2. The pilot's compass correction card is filled in during the residual swing of the compass.

825 - 3. The compass correction card tells the pilot the standby compass heading to be flown in order to fly a desired actual magnetic heading.

CHAPTER 3

826 - 1. A recorder unit, a magazine, an accelerometer sensor, a test switch, and a recorder-inoperative light.

826 - 2. To an AC bus that remains powered in the event of electrical power failure on the aircraft.

826 - 3. The system receives signals from the aircraft compass system, the accelerometer, and the pitot static system.

826 - 4. The medium passes through the recorder in one direction, and scribe marks are made on one side. Then the medium is taken from the takeup position, placed in the supply position, and run through the recorder again, so that scribe marks are made on the other side.

826 - 5. Power is routed through the contacts to keep the recorder unit from operating while ground maintenance is being performed on the aircraft.

826 - 6. The recorder-inoperative light.

826 - 7. The operational limits of the accelerometer are -3g to +6g.

827 - 1. A constant speed timing and actuating motor.

827 - 2. The acceleration channel.

827 - 3. A scribe engraves an upper mark for northerly headings and a lower mark for southerly headings.

827 - 4. The two signals are compared. If they are different, an error signal is developed.

827 - 5. The servomotor mechanically drives the gearbox, the north-south switch, and the rotor of the heading transformer synchro.

827 - 6. The operational range of the altitude channel is -1,000 feet to +50,000 feet.

827 - 7. The altitude channel uses only static pressure. The airspeed channel uses both pitot and static pressure.

828 - 1. An aircraft structural integrity program is necessary to predict the life expectancy of an airframe.

828 - 2. The Life History Recording System and the Flight Loads Data Recording System.

828 - 3. The flight parameters which may be monitored under the AIS Program include: pitch and yaw rate; rudder, elevator, and flap position; nose wheel steering; airspeed; altitude; vertical acceleration; pressurization; structural loads; taxi speed; strut compression; landing gear position; fuel load; and documentary data which is manually inserted into the recorder.

828 - 4. The aircraft serial number, gross weight, total fuel weight, configuration, and date.

829 - 1. The ASIP recorder is capable of recording 240 9-bit characters per second.

829 - 2. One-half inch magnetic tape.

829 - 3. The aircraft serial number, gross weight, fuel weight, base and mission codes, aircraft configuration code, and the date of the flight.

829 - 4. The REC FAILURE, SUP DATA, MUX FAILURE, and TEST lights.

829 - 5. It prevents operation of the system unless the access door is closed and locked.

829 - 6. Depress the center spring lock.

829 - 7. The tape remaining indicator has a pointer that moves across a fixed scale to indicate the percent of tape remaining.

830 - 1. c, d, e, f, g, l.
830 - 2. d.
830 - 3. g.
830 - 4. c, l.
830 - 5. h, i, m.
830 - 6. n.
830 - 7. e.
830 - 8. b.
830 - 9. a.
830 - 10. j.

831 - 1. The LHRS BIT switch uses 28-volt DC power from the aircraft bus.

831 - 2. The recorder will not operate if a tape cartridge has not been installed or if the cartridge access door is not completely closed.

831 - 3. 115-volt AC power is applied to the recorder power supply when the power control relay is energized.

831 - 4. When the power supply is turned on, a master reset pulse is triggered to reset the logic circuits.

831 - 5. The record motor operates off of a 60 Hz 2-phase power from the record motor driver.

831 - 6. Thirty seconds.

831 - 7. To prevent calibration data from being recorded during flight.

831 - 8. At the conclusion of the test cycle, the flip-flop is reset, the power control relay deenergizes, and the test light goes out.

831 - 9. About 40 seconds.

832 - 1. The rate of tape movement is sensed by a light and photocell arrangement. The light source is located on one side of a wheel with eighty equally spaced holes in its outer edge. A photocell mounted on the other side of the wheel generates electrical pulses each time light coming through the holes strikes it. The pulses generated by the photocell as the wheel turns are applied to a counter circuit which determines the rate of tape movement.

832 - 2. If the tape speed is not within specified limits, the REC failure light comes on and stays on.

832 - 3. The REC failure light blinks to indicate an end of tape condition.

833 - 1. 26 channels. 240 times per second.
833 - 2. The recorder power supply.
833 - 3. Analog (sensor) inputs. Discrete inputs (airplane events).

834 - 1.
(1) h, k, l.
(2) a, c, d.
(3) o.
(4) m, n.
(5) i.
(6) f.
(7) p.
(8) q.
(9) g.
(10) e.
(11) b.
(12) r.

835 - 1. A temperature compensator, an active strain gage, and two 350-ohm bridge completion resistors.

835 - 2. The active leg of the bridge circuit is the active strain gage located at the monitored structural area.

835 - 3. Axial stress at the selected locations.
835 - 4. In the strain gage amplifier.
835 - 5. In two stages.
835 - 6. 10-volts DC from the converter-multiplexer.
835 - 7. 0 to 5 volts.

835 - 8. Compressive strain is measured on the low end of the scale from 0 to 2.5 volts and tension strain is measured on the high side of the scale from 2.5 to 5 volts.

836 - 1. Use the built-in-test (BIT) routine.

836 - 2. Transducer, accelerometer, system events, total fuel quantity, and strain gage checks are independent procedures.

836 - 3. The recorder will not operate unless the tape cartridge door is closed, because the door actuates a built-in switch.

836 - 4. To check these press-to-test bulbs.

836 - 5. When lit they indicate a component failure.

836 - 6. You need a multimeter and a TTU-205 test set.

836 - 7. You take voltage measurements at the aircraft wiring connector that connects to J1 on the converter multiplexer.

836 - 8. So that it can be turned to check its output.

836 - 9. Take *voltage readings* at the *input connector to the converter-multiplexer.*

836 - 10. Turning an accelerometer upside down will give an output equivalent to -1G.

836 - 11. By measuring its resistance.

836 - 12. Anytime you are unable to balance the amplifier or when depot informs you of improper tape readings.

836 - 13. You may have to perform some preliminary procedures such as closing entrance hatches or installing jumper wires.

836 - 14. Use a DC digital voltmeter. Connect it between the output jack on the amplifier and aircraft ground.

836 - 15. Use the ACTE/BRDG switch.

837 - 1. Four duties relating to the ASI Program that are normally assigned to the instrument specialist are (1) operationally check the ASIP system, (2) set in the necessary documentary data before each flight, (3) replace tape cartridges as necessary, and (4) process and mail used tapes to the depot facility.

837 - 2. The amount of tape remaining must be checked before every flight.

837 - 3. A configuration code (from those listed in the TO) is dialed in the ASIP recorder to show the aircraft configuration for each flight.

838 - 1. You check an ASIP recorder or converter-multiplexer by performing the BIT routine.

838 - 2. A failure light indicates a defective component.

838 - 3. Troubleshoot the system and correct the malfunction before you reset it.

838 - 4. Incorrect input data may be detected by analysis of tape from a previous flight. Your indication of such incorrect data would be a message or phone call from the depot facility.

838 - 5.
(1) h, b.
(2) g.
(3) f, g.
(4) a, j, i, g.
(5) b.

839 - 1. Removal and installation of the recorder, converter-multiplexer, transducer, accelerometer, and strain gage amplifiers can be done on the flight line using common hand tools.

839 - 2. The strain gages.

839 - 3. If it is necessary to use the spare strain gage, you should check the resistance twice; once, before using it to determine if it is good. Check it again after it is installed to make sure your splices are good.

839 - 4. The accelerometer and the rate gyro.

839 - 5. Be careful not to let the cable snap back and damage the transducer.

839 - 6. To adjust the pulse rate integrator.

STOP- 1. MATCH ANSWER SHEET TO THIS EXERCISE NUMBER.
2. USE NUMBER 2 PENCIL ONLY.

EXTENSION COURSE INSTITUTE
VOLUME REVIEW EXERCISE

32551 05 22
LIQUID QUANTITY, UTILITY, AND RECORDING SYSTEM

Carefully read the following:

DO's:

1. Check the "course," "volume," and "form" numbers from the answer sheet address tab against the "VRE answer sheet identification number" in the righthand column of the shipping list. If numbers do not match, return the answer sheet and the shipping list to ECI immediately with a note of explanation.
2. Note that item numbers on answer sheet are sequential in each column.
3. Use a medium sharp #2 black lead pencil for marking answer sheet.
4. Write the correct answer in the margin at the left of the item. (When you review for the course examination, you can cover *your* answers with a strip of paper and then check your review answers against your original choices.) After you are sure of your answers, transfer them to the answer sheet. If you *have* to change an answer on the answer sheet, be sure that the erasure is complete. Use a clean eraser. But try to avoid any erasure on the answer sheet if at all possible.
5. Take action to return entire answer sheet to ECI.
6. Keep Volume Review Exercise booklet for review and reference.
7. If *mandatorily* enrolled student, process questions or comments through your unit trainer or OJT supervisor. If *voluntarily* enrolled student, send questions or comments to ECI on ECI Form 17.

DON'Ts:

1. Don't use answer sheets other than one furnished specifically for each review exercise.
2. Don't mark on the answer sheet except to fill in marking blocks. Double marks or excessive markings which overflow marking blocks will register as errors.
3. Don't fold, spindle, staple, tape, or mutilate the answer sheet.
4. Don't use ink or any marking other than a #2 black lead pencil.

NOTE: **NUMBERED LEARNING OBJECTIVE REFERENCES ARE USED ON THE VOLUME REVIEW EXERCISE.** in parenthesis after each item number on the VRE is the *Learning Objective Number* where the answer to that item can be located. When answering the items on the VRE, refer to the *Learning Objectives* indicated by these *Numbers*. The VRE results will be sent to you on a postcard which will list the *actual* VRE *items you missed*. Go to the VRE booklet and locate the *Learning Objective Numbers* for the items missed. Go to the text and carefully review the areas covered by these references. Review the entire VRE again before you take the closed-book Course Examination.

MULTIPLE CHOICE

Note to Student: Consider all choices carefully and select the *best* answer to each question.

1. (800) The sensing element in the tank unit of a DC liquid level system senses

   a. density change.
   b. pointer movement.
   c. electrical impulses.
   d. mechanical movement.

2. (800) Which of the following components prevents fuel and fuel vapors from entering the electrical compartment of a DC liquid level tank unit?

   a. The gasket.
   b. The bellows.
   c. The fulcrum pipe.
   d. The float arm assembly.

3. (800) How many legs of the bridge circuit are made up by the resistance strip of the DC liquid level system?

   a. 1.
   b. 2.
   c. 3.
   d. 4.

4. (800) What governs the strength of the magnetic field around the deflection coils in the indicator of a DC liquid level system?

   a. Position of the wiper arm.
   b. Amount of stator movement.
   c. Amount of rotor movement.
   d. Accuracy of the indication.

5. (801) What position does the pointer assume when electrical power is removed from the DC liquid level system and why?

   a. A hairspring returns the pointer to off scale below empty.
   b. A balance mechanism causes the pointer to go to off scale full.
   c. A bar magnet pulls the pointer to off scale below empty.
   d. The pointer remains at the last indication because the rotor is unrestrained.

6. (801) When troubleshooting a DC liquid level system, if a no-power indication is apparent, a check should first be made for

   a. a short.
   b. a broken wire.
   c. an open wiper contact.
   d. a blown fuse.

7. (801) The test set used to test DC liquid-level components is the

   a. MD-1 tester.
   b. MD-2A tester.
   c. TF-20 tester.
   d. 0-1 tester.

8. (801) If the pointer travel is *not* equal when you are checking a DC liquid level tank unit, how can you correct the error?

   a. Turn the R+ screw.
   b. Turn the R- screw.
   c. Pivot the contact arm.
   d. Adjust the float arm.

9. (802) How does an increase of the K factor affect the capacitance of a capacitor?

   a. Capacitance decreases.
   b. Capacitance increases.
   c. Capacitance may increase or decrease.
   d. Capacitance remains the same.

10. (802) The capacitance of a fuel-quantity tank unit is measured in which part of the system?

    a. Amplifier.
    b. Bridge.
    c. Servomotor.
    d. Compensator.

11. (803) The two factors of a capacitance tank unit that remain constant are the

a. area of the plates and the distance between the plates.
b. area of the plates and the dielectric.
c. distance between the plates and the dielectric.
d. material between the plates and the dielectric.

12. (803) The leg of the bridge circuit of the fuel-quantity indicating system in which the rebalancing pot is usually placed is the

a. amplifier leg.
b. millivoltmeter leg.
c. variable capacitor leg.
d. reference capacitor leg.

13. (804) The leg of the bridge circuit of the fuel-quantity indicating system in which the EMPTY adjustment pot is placed is the

a. tank unit leg.
b. amplifier leg.
c. millivolt leg.
d. reference capacitor leg.

14. (804) In the capacitance fuel-quantity system, the purpose of the compensator is to compensate for changes in the

a. dielectric constant.
b. voltage at the power source.
c. reference leg of the bridge.
d. amplifier leg of the bridge.

15. (804) One significant characteristic of the regular tank unit and the compensator is that the compensator

a. is always larger.
b. is always smaller..
c. is the same size.
d. uses a different dielectric.

16. (804) The number of compensators installed in one fuel tank

a. is one in each tank.
b. is one for each tank unit.
c. varies according to type and model of aircraft.
d. varies according to the type of fuel being used.

17. (805) Noncharacterized tank units have

a. uniform plate areas.
b. nonuniform plate areas.
c. nonuniform cross-sectional areas.
d. cylindrical capacitors of six concentric tubes.

18. (805) More than one tank unit would be installed in a fuel tank to

a. reduce flunctuations in fuel-quantity indication.
b. reduce the tank unit resistances.
c. reduce voltage in tank as a safety feature.
d. obtain a higher signal for indicator operation.

19. (806) When a simulator is used in a fuel-quantity system, its capacitance is set at

a. zero.
b. full.
c. empty.
d. half full.

20. (806) In an aircraft with a selective fuel-quantity indicating system, when the feed tank switch is placed in the FEED TANK CHECK position, the fuel-quantity indicator will indicate

a. zero.
b. fuel in master feed tank.
c. total fuel in all the tanks.
d. an off-scale full indication.

21. (807) The discriminator output current in the bridge amplifier of the capacitance fuel-quantity system is

a. straight DC.
b. pulsating DC.
c. square wave DC.
d. sawtooth wave DC.

22. (807) In the bridge amplifier of the capacitance fuel-quantity system, the discriminator is controlled by

a. negative bias.
b. positive bias.
c. cathode bias.
d. plate bias.

23. (808) The capacitance fuel-quantity indicator is calibrated to measure

a. pounds of fuel used.
b. gallons of fuel used.
c. pounds of fuel available.
d. gallons of fuel available.

24. (808) What is the signal-sensing device in a capacitance fuel-quantity indicator?

a. A syncro motor.
b. A servoloop.
c. A single-phase induction motor.
d. A two-phase induction motor.

25. (809) A coax cable is used in the capacitance fuel-quantity system to

a. efficiently transfer electrical signals.
b. stabilize the capacitance of the tank unit.
c. increase the voltage drop across the amplifier.
d. stabilize the capacitance of the reference capacitor.

26. (809) What type of connectors are used in the capacitance fuel-quantity indicating system?

a. Banana plugs.
b. Dual bayonet plugs.
c. Standard AN connector plugs and receptacles.
d. Single conductor bayonet-locking mechanism.

27. (810) What are the usual power requirements for the transistorized fuel-quantity indicator that incorporates its own bridge circuit?

a. 115 VAC.
b. 26 VAC, 28 VDC.
c. 115 VAC, 26 VAC.
d. 115 VAC, 28 VDC.

28. (810) When using the correction chart for the MD-1, the correction factors listed in the Add column are

a. added to the desired capacitance to determine the dial setting.
b. subtracted from the desired capacitance to determine the dial setting.
c. subtracted from the dial reading to obtain a desired capacitance.
d. used only in calibrating the tester.

29. (811) Maintenance of the MD-1 tester by the line mechanic includes

a. repairing modules.
b. modifying the tester.
c. calibrating the tester.
d. replacing the desiccator.

30. (811) What tester is designed to test tank units of the capacitance fuel-quantity system while the tank units are installed in the aircraft?

a. MD-1.
b. MP-1.
c. MD-2A.
d. N-3A.

31. (812) The linearity check of a liquid-quantity indicator checks for what type of error?

a. Scale error.
b. Range error.
c. Pointer slippage.
d. Response time.

32. (812) The dead-spot check, performed during bench check of indicators in the capacitance fuel-quantity systems, determines

a. the lag between rotor movement and capacitance change.
b. if the EMPTY and FULL adjustments are properly adjusted.
c. the serviceability of an indicator throughout its full range.
d. the time it takes the indicator pointer to travel from stop to stop.

33. (813) When complying with a preferred method of calibration, the fuel tanks should be

a. full.
b. empty.
c. one-half full.
d. at least level.

34. (813) When calibrating a fuel-quantity indicator,

a. approach the test points from a higher reading to simulate fuel being used.
b. move the pointer slightly below the value being tested to avoid gear backlash error.
c. tap the gage firmly on the cover glass to remove any friction error.
d. keep the press-to-test switch depressed throughout the calibration procedure.

35. (813) Most fuel-quantity system malfunctions occur because of

a. wiring troubles.
b. faulty tank units.
c. rusted compensators.
d. burned-out amplifiers.

36. (813) The most probable cause of the capacitance fuel-quantity indicator pointer rotating continuously counter clockwise would be

a. a defective indicator motor.
b. a shorted coaxial lead.
c. an open compensator lead.
d. an open coaxial lead.

37. (814) When you must replace an internally-mounted fuel probe, why should synthetic fabrics *not* be worn inside the aircraft fuel tank?

a. Aviation fuel will dissolve many synthetic fabrics.
b. Synthetic fabrics tend to build up radiation charges which will interfere with the operation of a capacitance system.
c. Synthetic fabrics tend to build up static electrical charges which could ignite fuel vapors when discharged.
d. When in contact with aviation fuel, many synthetic fabrics produce deadly fumes.

38. (815) The wipers of the DC position transmitter make contact with a resistance strip having taps spaced

a. 60° apart.
b. 90° apart.
c. 120° apart.
d. 180° apart.

39. (815) How are flap-position indicators compensated for coil resistance changes caused by temperature?

a. By the use of a calibrated hairspring attached to the rotor shaft.
b. By the use of a bimetallic spring attached to the pointer shaft.
c. By the use of mickel windings in the transmitter.
d. Symmetrical arrangement of the coils eliminates the need for temperature compensation.

40. (816) How many people are required to safely operationally check a flap- position indicating system?

a. 1.
b. 2.
c. 3.
d. 4.

41. (817) If power to a position-indicating system fails, the indicator pointer will

a. oscillate.
b. indicate normal.
c. remain at its last indication.
d. point to an off-scale indication.

42. (817) What usually causes the most malfunctions in a position-indicating system?

a. Open, dirty, or corroded resistance strip in the transmitter.
b. Loss of magnetism or a sticky movement in the indicator.
c. Open or shorted electrical connectors or wiring on the aircraft.
d. Loose, bent, or rusted drive linkage for the transmitter.

43. (818) A landing gear position indicator is best described as a

a. DC solenoid-type indicator.
b. AC dynamometer type.
c. synchro indicator.
d. selsyn indicator.

44. (818) What will a landing gear indicator show if power to the system is lost?

a. It will remain at the last indication.
b. It will show OFF.
c. It will show gear up or down but unlocked.
d. It will display a cross-hatched warning symbol.

45. (819) What caution should be observed when you operationally check a landing gear position-indicating system?

a. The switches should be actuated only if you know for sure that they will operate only the indicating system.
b. The switches should be actuated only if you remove electrical power from the aircraft.
c. The switches should be actuated only after jumper wires have been installed across them.
d. The switches should be actuated only after the aircraft has been put on jacks and safety pins have been installed.

46. (819) What is required in order to check the switch mechanical-actuating mechanism for proper adjustment?

a. A micrometer.
b. An H-1 tester.
c. A retraction test.
d. A functional check flight.

47. (820) If the landing gear indicator shows the gear down and locked when the gear is up and locked, the most probable cause of trouble is

a. an open up lock switch.
b. a shorted up lock switch.
c. an open down lock switch.
d. a shorted down lock switch.

48. (821) What force, measured by the accelerometer, creates more strain on the aircraft and its crew than most others?

a. Gravity.
b. Thrust.
c. Centrifugal.
d. Hyperbolic.

49. (821) The accelerometer is designed to indicate acceleration action along which axis of the aircraft?

a. The longitudinal axis.
b. The vertical axis.
c. The lateral axis.
d. The roll axis.

50. (822) What is incorporated in the accelerometer to allow the auxiliary pointers to turn only in one direction?

a. A hairspring.
b. Mechanical stops.
c. A magnetic coupling device.
d. A ratchet and pawl assembly.

51. (822) Accelerometer operation is based upon the principles of

a. gravity and antigravity.
b. inertia and acceleration.
c. static and dynamic stability.
d. electromotive force and resistance.

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52. (822) If the accelerometer indicates +1 g in straight and level flight and you are able to duplicate this indication on the ground, what is wrong?

a. Nothing is wrong. It is the normal indication.
b. The accelerometer is probably locked or stuck.
c. The accelerometer is probably improperly mounted.
d. The accelerometer just requires adjustment.

53. (823) An inspection requirement for the accelerometer is to insure that the

a. auxiliary pointers indicate a +1 g when reset by the knob.
b. main pointer indicates a +1 g and the auxiliary pointers indicate the maximum g's recorded during the last flight.
c. auxiliary pointers indicate an 0 g.
d. main pointer indicates a +1 g and the auxiliary pointers indicate an 0 g.

54. (823) When you are checking an accelerometer, what should it indicate when it is positioned upside down?

a. -1 g.
b. 0 g's.
c. +1 g.
d. +2 g's.

55. (824) The compensating mechanism in the standby magnetic compass consists of what?

a. Two sets of opposing bellows.
b. A set of two hairsprings.
c. Two sets of bar magnets.
d. A set of two bimetallic springs.

56. (824) A deviation error is known as the difference between

a. true north and magnetic north.
b. the aircraft magnetic heading and the compass reading.
c. the magnetic and remote compass readings.
d. the aircraft platitude and true north.

57. (824) When using a sight compass to swing an aircraft, the sight compass is aligned along which axis of the aircraft?

a. Longitudinal.
b. Latitudinal.
c. Vertical.
d. Horizontal.

58. (824) Which of the following items should *not* be carried, worn, or used when swinging a compass?

a. Brass screwdriver.
b. Lead pencils.
c. Metal-framed glasses.
d. Loose-fitting clothes.

59. (825) During the compensation swing of a standby compass, you find errors of +6° at N, +3° at E, -2° at S, and +1° at N. What is the index error?

a. +3°.
b. -3°.
c. +2°.
d. -2°.

60. (825) When swinging the standby compass, coefficient c is applied to

a. the compass mount (index error).
b. the N-S compensator adjustment screw.
c. the E-W compensator adjustment screw.
d. the remote polyplane compensator.

61. (825) The pilot's compass correction card, DD Form 1613, is filled out when performing a

a. compensating swing.
b. variation swing.
c. deviation swing.
d. residual swing.

62. (825) The detachable portion of the DD Form 1613, when completed, is kept with the aircraft standby compass. What do you do with the portion on which you made your computations?

a. Destroy it because its purpose has been served.
b. Send it to analysis along with the AFTO Form 349 for keypunching.
c. Leave it with the AFTO Form 781, Aircraft Maintenance Records.
d. File it in your shop for future reference.

63. (826) The flight data recorder system records information on

a. altitude and ground speed.
b. ground speed, airspeed, and compass heading.
c. compass heading, airspeed, G-forces, and altitude.
d. compass heading, ground speed, G-forces, and altitude.

64. (826) The electrical power requirements for the flight data recorder operation are

a. 115 V AC and 28 V DC.
b. 115 V AC and 26 V AC.
c. 26 V AC and 28 V DC.
d. 100 V DC and 26 V AC.

65. (826) The flight data recorder system test switch is wired in parallel with the external and auxiliary power so that it can be used

a. to flight check the recorder.
b. when checking the recorder on the ground.
c. as a backup if the contactor fails.
d. to isolate the recorder unit during flight.

66. (827) A permanent record of the aircraft's inflight information is engraved on the recording medium by

a. a logic computer.
b. an intermittent mechanism.
c. a needle.
d. scribes.

67. (827) Which of the following channels of the flight data recorder uses both pitot and static pressure?

a. Heading.
b. Altitude.
c. Airspeed.
d. Accelerometer.

68. (827) How is heading information recorded in the flight data recording system?

a. By a scribe.
b. By a magnetic write head.
c. By two scribes.
d. By two magnetic write heads.

69. (828) Which of the following general statements describes systems used in support of the Aircraft Structural Integrity Program (ASIP)?

a. Each of the systems is a single-channel system which records engine operating statistics.
b. Each of the systems is a dual-channel system which records flight parameters in relation to flight plans.
c. Each of the systems is an eight-track magnetic tape system which records oral inputs from crew members and manually inserts documentary data.
d. Each of the systems is a multichannel system which records flight parameters relating to structural loads.

70. (828) The flight parameters normally recorded by an ASIP system include

a. airspeed, altitude, vertical acceleration, and structural loads.
b. airspeed, altitude, rate of climb, gross weight, fuel distribution, and weather conditions.
c. ground speed, elevation, total fuel weight, passenger configuration, and structural design.
d. speed, height, duration of flight, autopilot operation, fuel distribution, and improper crew member actions.

71. (828) The documentary data inputs to the ASIP recorder are controlled by

a. dialing in the data using rheostat knobs on the front of the converter-multiplexer.
b. positioning digital thumbwheel selector switches on the front of the recorder.
c. inserting prerecorded cassette-type tapes into the system control unit.
d. inserting digital formatted data into the control panel in the cockpit.

72. (828) The documentary data used by an ASIP system is

a. a one-time entry for each aircraft.
b. recorded before each flight.
c. recorded after each checkout procedure.
d. updated throughout each flight.

73. (829) During normal operation of an ASIP recorder, what indicates that the end of the tape has been reached?

a. The MUX failure light flashes.
b. The SUP data light illuminates steadily.
c. The RECORDER off light illuminates steadily.
d. The REC failure light flashes.

74. (829) The tape remaining indicator on an ASIP recorder cartridge uses a pointer that is read against a fixed scale to indicate

a. hours of recording time remaining.
b. feet of tape remaining.
c. meters of tape remaining.
d. percentage of tape remaining.

75. (829) What is the capacity of an ASIP recorder tape?

a. 10 hours.
b. 12.5 hours.
c. 15 hours.
d. 20 hours.

76. (830) To which unit is the data from the ASIP sensors first applied?

a. The recorder.
b. The signal transducers.
c. The converter-multiplexer.
d. The documentary data converter.

77. (830) Which circuit in the converter-multiplexer conditions the input signals from the sensors to provide a common 0 to +5-volt range regardless of the normal range or polarity of the signal?

a. Scaling circuit.
b. Filter circuit.
c. Analog to digital converter.
d. DC to DC converter.

78. (830) In which unit of an ASIP system is the documentary data mixed with the sensor and airplane events inputs?

a. In the digital multiplexer of the recorder.
b. In the scaling circuit in the converter-multiplexer.
c. In the digital multiplexer of the converter-multiplexer.
d. In the analog multiplexer of the converter-multiplexer.

79. (830) How frequently are the flight parameters that are monitored recorded by an ASIP recorder?

a. Twice a second.
b. Once a second.
c. Once every two seconds.
d. Once every five seconds.

80. (831) How are the logic circuits in the converter-multiplexer reset?

a. The press-to-reset button must be depressed.
b. Dial zeros in using the documentary data thumbwheels.
c. When the power supply is turned on, a master reset pulse is triggered to reset them.
d. the CAL DEACTIVATE switch must be cycled between the CAL ACTIVATE and CAL DEACTIVATE position.

81. (831) When using the built-in-test to check the recorder and converter-multiplexer, how long does the BIT cycle take?

a. 20 seconds.
b. 40 seconds.
c. 60 seconds.
d. 90 seconds.

82. (832) What sensor is used in the ASIP recorder to monitor the tape speed?

a. The rate generator.
b. The digital timer.
c. The RPM indicator.
d. The photocell.

83. (832) In the ASIP recorder, what signals an end-of-tape condition?

a. A conductive metallic strip at the end of the tape completes a circuit which causes the REC failure light to come on.
b. A microswitch opens the light circuit causing the system ON light to extinguish.
c. A photocell generates a small DC signal which operates and end-of-tape light.
d. A tape tension switch illuminates the MUX failure light.

84. (833) How many channels does the converter-multiplexer have to process the different inputs?

a. 11.
b. 17.
c. 26.
d. 29.

85. (833) What are the power requirements for the converter-multiplexer?

a. 115 VAC, 400 Hz, single phase and 28 VDC.
b. 115 VAC, 60 Hz, three phase and 26 VDC.
c. 115 VAC, 400 Hz, three phase; 26 VAC, 400 Hz, single phase; and 28 VDC.
d. 115 VAC, 400 Hz, single phase and various DC voltages.

86. (833) The converter-multiplexer is capable of sampling input signals at what maximum rate?

a. 100 times per second.
b. 240 times per second.
c. 400 times per minute.
d. 800 times per minute.

87. (834) The airspeed and altitude transducer used in an ASIP system provides electrical analog signals in what ranges?

a. 0 to 900 knots and -1500 to 100,000 feet.
b. 50 to 1000 knots and 0 th 75,000 feet.
c. 0 to 800 knots and -1000 to 80,000 feet.
d. 30 to 750 knots and -1800 to 50,000 feet.

88. (834) The elapsed time indicator on the airspeed and altitude transducer is powered by

a. the airplane 115 volt bus.
b. the aircraft instrument power transformer.
c. the recorder power supply.
d. the DC to DC converter.

89. (834) The vertical accelerometer used in an ASIP system senses accelerations along which axis?

a. The gravitational axis.
b. The vertical axis only.
c. The longitudinal axis only.
d. The vertical and longitudinal axes.

90. (834) Which component of an ASIP system translates a large mechanical movement into an accurate linear DC-voltage signal?

a. Pulse rate integrator.
b. Pressurization transducer.
c. Position transducer.
d. Converter-multiplexer.

91. (835) What type of circuit is used to measure stresses and strains in critical areas of the fuselage and wings?

a. A resistance bridge circuit.
b. An inductive bridge circuit.
c. A logic circuit.
d. A digital clock circuit.

92. (835) The type of electrical circuit used to determine the structural integrity of an aircraft consists of

a. a crack detectoin photocell, a two stage amplifier, and a warning light.
b. an air density compensator, an active leg, and two 500 uf bridge completion capacitors.
c. a stress detector, a strain gage, a bridge completion resistor, and a galvanometer type indicator.

93. (835) The strain gage amplifier amplifies the input signal in how many stages before it is sent to the multiplexer?

a. 1.
b. 2.
c. 3.
d. 4.

94. (835) What is the output of the strain gage amplifier?

a. -5 volts to +5 volts DC.
b. 0 to 5 volts DC.
c. 0 to 10 volts DC.
d. 5 to 10 volts DC.

95. (836) What does the built-in-test (BIT) routine of an ASIP system check?

a. The recorder only.
b. The converter-multiplexer only.
c. The recorder and the converter-multiplexer.
d. All of the system except the strain gages.

96. (836) What is the purpose of the MUX, SUP DATA, and REC lights on the ASIP recorder?

a. They illuminate to show that the converter, recorder, and supplement data inputs are present.
b. They indicate the presence of electrical power at the applicable components when lit.
c. They indicate a component failure when they remain lit.
d. They indicate erroneous inputs when lit.

97. (836) The TTU-205 test set is required to check which component of an ASIP system?

a. The airspeed and altitude transducer only.
b. The airspeed and altitude transducer and the converter-multiplexer.
c. The recorder unit only.
d. The converter-multiplexer and the recorder.

98. (836) When an ASIP accelerometer is placed on its side with the sensing axis parallel to the earth's surface, its output should be

a. 1.25 volts representing +1 G.
b. 0 volts representing +1 G.
c. 1.25 volts representing 0 G.
d. 0 volts representing 0 G.

99. (836) Normal output of the ASIP accelerometer during straight and level flight is

a. 0 volts.
b. -1.25 volts.
c. +1.25 volts.
d. 0 Gs.

100. (836) When would a strain gage resistance check be performed?

a. Only if it is suspected of being defective.
b. If erratic system operation is reported by the flight crew.
c. During all major hourly aircraft inspections.
d. When unreliable frequency outputs are obtained.

101. (836) Where is the DC digital voltmeter connected to check the balance of the strain gage amplifier?

a. Between the NULL trimpot and ground.
b. Between the OUT jack and ground.
c. Across the gain control outputs.
d. Across the NULL trimpot.

102. (837) Who is normally responsible for manually entering the documentary data into the ASIP recorder?

a. The crew chief.
b. The flight crew.
c. The instrument specialist.
d. All the above.

103. (837) What must be done after you replace the tape cartridge in an ASIP recorder?

a. The used tape must be mailed to the processing facility
b. An operational check must be accomplished.
c. The documentary data must be verified and updated as necessary.
d. All of the above.

104. (838) If the ASIP system transducer produced no digital output, what would be the likely cause(s)?

a. Converter-multimplexer or accelerometer.
b. Transducer or strain gage amplifier.
c. Converter-multiplexer or transducer.
d. Accelerometer or strain gage amplifier.

105. (838) Which ASIP system condition would *not* cause the REC FAILURE light to illuminate during a BIT test?

a. Out of tape.
b. Defective recorder.
c. Defective tape cartridge.
d. Defective converter-multiplexer.

106. (838) An out-of-tape condition is signaled by illumination of which of the following failure lights?

a. MUX FAILURE.
b. REC FAILURE.
c. SUP FAILURE.
d. Multiple failure lights (MUX, REC, SUP).

107. (839) The ASIP recorder CAL DEACTIVATE switch must be in the

a. CAL position to operationally check the system.
b. DEACTIVATE position during normal operation.
c. CAL position during normal operation.
d. DEACTIVATE position to balance the system.

108. (839) Besides the strain gage amplifier, which ASIP system component requires adjustment after installation?

a. Accelerometer.
b. Strain gage.
c. Converter-multiplexer.
d. Pulse rate integrator.

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AVIONICS INSTRUMENT SYSTEMS SPECIALIST

(AFSC 32551)

Volume 6

Flight and Navigation Instruments

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Preface

THIS SIXTH volume of the *Avionics Instrument Systems Course* deals with the instruments and associated systems that are required to fly and navigate all modern aircraft. Your study of these instruments and systems includes the way they operate; inspection, operational check, and bench check requirements; and trouble analysis.

Chapter 1 explains pitot and static air pressure systems and the basic instruments used in these systems.

Chapter 2 progresses to a more complicated instrument system which also operates on pitot and static pressures. This is the Automatic Altitude Reporting System, normally referred to as the AIMS system.

Chapter 3 is devoted to the navigational systems used in guiding aircraft during flight. This chapter includes gyroscopic principles used in many directional guidance systems.

Chapter 4 combines several of the systems you will study in this volume into a special grouping called Vertical Scale Flight Instruments.

Chapter 5 deals with the angle-of-attack/stall warning system and with our most predominant optical navigation instrument, the sextant.

Chapter 6 discusses avionics instrument systems support equipment and its maintenance.

Illustrations are provided to clarify the text. The code numbers appearing on illustrations are for preparing agency identification only.

Oversize schematic diagrams are referred to as foldouts and are bound in the back of this volume. When the text refers to these foldouts, turn to the back and locate them.

Direct your questions or comments relating to the accuracy or currency of this volume to the course author: 3360 TCHTG/TTGU-F, ATTN: MSgt Lawrence B. Miller, Chanute AFB IL 61868. If you need an immediate response, call the author, AUTOVON 862-2041, between 0800 and 1600 (CST), Monday through Friday. *(NOTE: Do not use the suggestion program to submit changes or corrections for this course.)*

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This volume is valued at 42 hours (14 points).

Material in this volume is technically accurate, adequate, and current as of August 1981.

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NOTE: In this volume, the subject matter is developed by a series of student-centered objectives. Each of these carries a three-digit alphanumeric identifier and is in boldface type. Each sets a learning goal for you. The text that follows the objective gives you the information you need to reach that goal. The exercises following the information give you a check on your achievement. When you complete them, see whether your answers match those in the back of this volume. If your response to an exercise is incorrect, review the objective and its text.

Basic Pitot-Static Systems

ONE GROUP of aircraft instruments is known as the pitot-static instruments. They indicate aircaft speed, rate of climb or dive, and altitude. This chapter discusses the pitot-static system and the instruments used with it. You must know the system and its instruments to repair it.

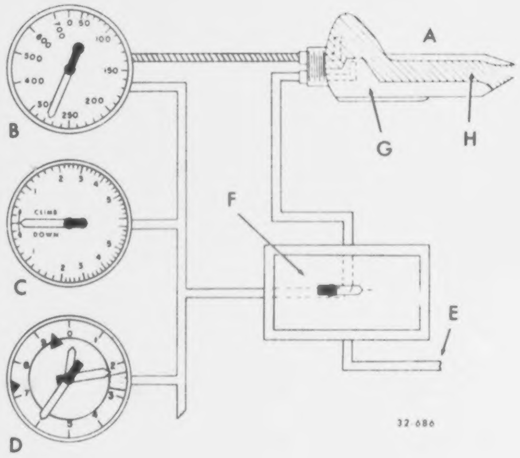
1-1. Common Pitot-Static Components

The pitot-static system consists of three major parts. These parts are the sensors pitot head and static ports which are sometimes located on the pitot head), the connecting tubing, and the pitot-static instruments. In addition to the very basic instruments (airspeed indicator, altimeter, and vertical velocity indicator), we will also discuss some advanced variations of these instruments.

A01. Identify the purpose of pitot tubes and static ports and specify their functions and characteristics.

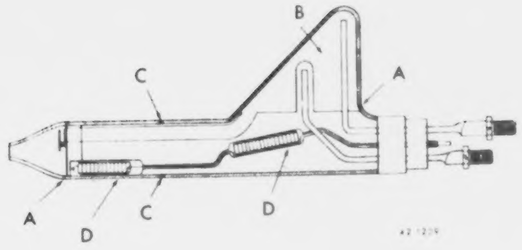
Pressure Sensors. A simplified pitot-static system is shown in figure 1-1. The pitot tube (head) is item A in the figure. It is called a pitot-static tube because it has the static ports on it. The pitot-static head is used to obtain pitot and static pressures which are used for the operation of the airspeed indicator (B in fig. 1-1). Static pressure also operates the rate-of-climb indicator (C) and the altimeter (D). The tube is mounted along the longitudinal axis (parallel to the roll axis) of the aircraft in a place where the air is fairly calm. In figure 1-1, you will also find the alternate static source (E), the static pressure selector valve (F), the static chamber (G), and the pitot chamber (H).

The head is the beginning point of the system. It serves as the source of needed pressures. All types of heads sense the same pressures. All types of heads attain the same result. Figure 1-2 shows an inside view of a typical pitot-static tube. The pitot opening is at the forward end of the tube. Impact pressure passes through the opening to the pitot chamber (B). A baffle and standpipe are located in the tube. These help keep water and dirt out of the system. The water drains out the small drain holes (A). Static pressure holes (C) are located around the middle of the tube. These holes allow atmospheric pressure to enter the static chamber while the bottom static holes drain the static chamber. Always keep these small holes (A and C) clean and free of dirt. The connecting lines have tee connections in them. These tees are placed at the lowest point between



A. Pitot tube (head)
B. Airspeed indicator
C. Rate-of-climb indicator
D. Altimeter
E. Alternate static source
F. Static pressure selector valve
G. Static chamber
H. Pitot chamber

Figure 1-1. Pitot-static system.



A. Drain holes
B. Pitot chamber
C. Static pressure holes
D. Heating elements

Figure 1-2. Pitot-static tube.

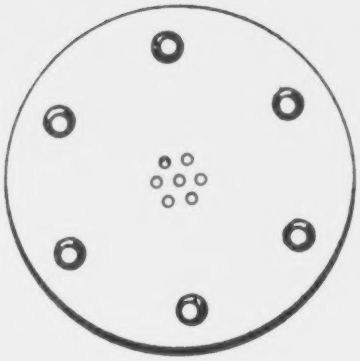


Figure 1-3. Flush mounted static port.

the tube and the instruments so you can drain any accumulated moisture from the system. Remove the plug periodically to drain the line. In later model aircraft, drain sumps fitted with petcocks drain the system.

Usually, you perform two inspections on the pitot-static tube. The first one is a visual inspection, and the other is an operational check that is part of the phase and postflight inspections. The heater prevents ice from forming on or in the tube. Ice forms when the aircraft is operating during icing (cold wet) conditions. The heater has two heating elements (D in fig. 1-2). These elements are connected in series and are powered by the aircraft electrical system. A toggle switch on the pilot's panel is used to control the heater. The heater should not be operated for more than 30 seconds on the ground. Operational checks can be pulled within this time.

If the heater becomes defective, the pitot-static tube may ice over. If this happens, the pilot can restore operation of the static system by selecting the ALTERNATE STATIC SOURCE. When the pilot selects this

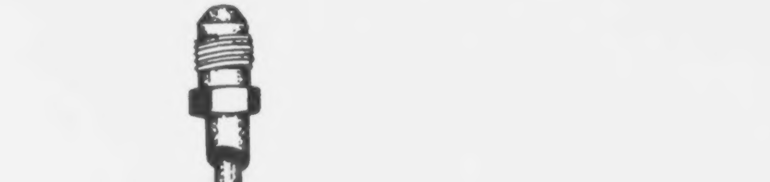


Figure 1-4. Type G pitot tube.

alternate source, the static ports are bypassed. The static system is vented to an unpressurized part of the aircraft. This change produces a small error in indications. This error is called *venturi action* and is caused by openings in the fuselage. The pressure of the alternate source is lower than atmospheric pressure.

On some aircraft, the pitot-static tube has been replaced by a flush-mounted static vent (fig. 1-3) and a type-G pitot tube (fig. 1-4). The vent is a round plate with seven small holes about its center. It also has a fitting on the back for connection to the system. The front fits flush with the skin of the aircraft. It is mounted between the midsection of the fuselage and the empennage. The exact location depends upon the aircraft. The static line may be connected to two vents, with one vent mounted on each side of the aircraft. Connecting the line to both vents compensates for any difference in pressure when the aircraft yaws. The pitot tubes are mounted parallel to the roll axis of the aircraft. There is no statis line connected to the tube.

The pitot-static system *must* be free from leaks. Make a thorough inspection for leaks and heater operation during your inspections. Be sure that the systems function properly. Between flights, shield the tubes from dust, oil, and foreign particles by placing the protective cover over the tube.

The pitot covers must be removed when the aircraft is ready for flight. A red streamer is attached to the pitot tube cover to remind the crew that the cover is still on the tube. This prevents the pilot from taking off and then finding that there is no airspeed indication. The pitot-static system is installed by the aircraft manufacturer and its location must not be altered. The pitot tube and mast (or boom) are made of dissimilar metals. Therefore, corrosion is likely. Paint zinc-chromate primer on the contact surfaces to check corrosion. The pitot tube should be installed while the primer is wet. The tube is secured by cadmium-plated screws to help prevent corrosion. Torque all pitot or static fittings as specified in the TO.

Faulty operation of the system can happen at any time. When a discrepancy is noted, the system must be repaired. The steps you must take are in the applicable technical ordes. Use the proper technical order for the specific aircraft. You will use test equipment that has been designed to test and repair the entire pitot-static system. There are various types of pitot-static field testers. For the specific tester to use on an aircraft, refer to the appropriate technical order. Our next discussion involves the indicators that are used in the pitot-static system.

Exercises (A01):

1. What is the purpose of the static holes in the bottom of the static chamber in the pitot tube?

2. Why does the change from the main to the alternate static pressure source cause a small amount of error in the aircraft altimeters?

3. On aircraft with a G-type pitot tube, how is static error due to aircraft yaw prevented?

4. Why is zinc-chromate primer used between the contact surfaces of the pitot tube and mast?

5. How would you determine what test equipment to use to check the pitot-static system on a particular aircraft?

A02. Identify the errors and the means for compensating for them on a standard airspeed indicator.

Airspeed Indicator. Standard airspeed indicators do not indicate the true speed of an aircraft. If the indicated airspeed (Vi) is to be compared to the true airspeed (Vt), there are three things to consider. The first is instrument error, caused by mechanical error within the instrument. The second is installation error, caused by the location and manner in which the pitot tube is installed. The third is density error, caused by altitude and temperature. This last error cannot be set for a given airspeed because of changing conditions. The two other errors can be determined, and a correction can be set up for a given speed. This correction is placed on a correction card that accompanies the instrument at all times. By applying instrument, installation, and density errors to the indicated airspeed, you get the calibrated airspeed (Vc).

The airspeed indicator installation is calibrated to develop corrections that offset errors. Some of these errors are caused by mechanical deficiencies in the indicator mechanism. Some are caused by the installation and design of the pitot tube. Others are caused by changes in the pressure distribution around the wing at various airspeeds. One method used to determine calibrated airspeed is the course method. In this procedure, true airspeed is determined by flying the aircraft over a measured course at the lowest safe altitude. Then the density error is added to the indicated airspeed. The result is the calibrated airspeed. The calibrated airspeed is found for indicated speeds at 20-mile-per-hour intervals over the normal speed range of the aircraft.

This is done by plotting the calibrated airspeed on a graph and comparing it with the indicated airspeed. The graph affords an accurate means of interpolation for the figures entered on the calibration card, which is kept near the instrument for which it is prepared. These filled-out cards are not interchangeable between instruments. To figure true airspeed, you also need to determine the proper density correction factor. When you combine this correction factor with the calibrated airspeed, you get true airspeed. Density correction can be obtained from a graph. Specific altitude and free-air temperature are needed to determine proper correction for density. This calibration is done in addition to shop calibration. In shop calibration, the indicator is adjusted for proper readings at various differential pressures applied to the instrument.

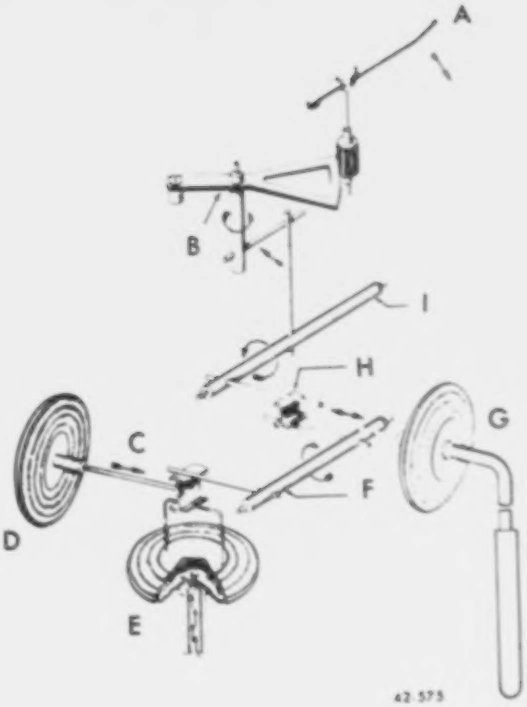
The standard airspeed indicator is exact at standard sea level pressure and temperature. It is inaccurate under all other conditions. Therefore, the true-airspeed indicator was developed.

Exercises (A02):

1. Identify the errors present in a standard airspeed indicator.

2. What means is used to compensate for errors present in a standard airspeed indicator?

3. What is needed to obtain the correct density correction factor.



A. Pointer
B. Sector gear
C. Altitude slide
D. Altitude aneroid
E. Airspeed diaphragm
F. Intermediate rocking shaft
G. Temperature diaphragm
H. Temperature slide
I. Main rocking shaft

Figure 1-5. Operation of true-airspeed indicator.

A03. State factors concerning the true-airspeed indicator and explain how it compensates for temperature changes.

True-Airspeed Indicator. You have just learned that, when standard airspeed indicators are used, corrections must be made to compensate for temperature and altitude (density) errors. This requires a certain amount of time, and at high speeds, time is very limited. Also, there is a chance of mathematical error. To solve this problem, instrument manufacturers designed a new airspeed indicator during World War II. The indicator computes and automatically corrects for errors caused by temperature and altitude changes. It was not completely accurate at first, but later models are more accurate.

The basic operation of the instrument is illustrated in figure 1-5. At the rear of the instrument, there are three connections. One admits pitot pressure into the diaphragm; one admits static pressure to the inside of the case; and the last one admits gas (methyl chloride) from the capillary-thermometer-sensing element. This element is mounted on the outside of the aircraft skin. The sensing elements inside the indicator are surrounded by static pressure. These include the airspeed diaphragm (E), the altitude aneroid (D), and the temperature diaphragm (G).

Increases in aircraft speed cause pitot pressure to increase. As it increases, pressure builds up inside the airspeed diaphragm (E in fig. 1-5). The diaphragm expands, pushing the altitude slide (C) upward. The upward motion rotates the intermediate rocking shaft (F). This action lifts the temperature slide (H). When the slide lifts, it turns the main rocking shaft (I), the sector gear (B), and the pointer (A). The altitude aneroid moves a slide toward the intermediate shaft as altitude increases. This action shortens the radius of the force-providing movement. Since the radius is shortened, the instrument indicates a speed increase.

Decreases in temperature cause the temperature diaphragm to contract, slowing down the pointer movement. Notice that the radius of rotation is lengthened. This arrangement corrects, at the same time, the indicated reading for altitude and temperature. The pointer moves at a rate proportional to the true airspeed.

The indicators that we have explained are used in a number of different aircraft. However, they cannot fulfill the needs of all aircraft, such as aircraft whose speed approaches or exceeds the speed of sound. The instruments for these faster aircraft must function in a range of maximum allowable speeds. They are called maximum-allowable-airspeed indicators and contain two independent mechanisms. One is an airspeed mechanism; the other is a Mach mechanism.

Exercises (A03):

1. State the type of gas used in the capillary-thermometer-sensing element of the true-airspeed indicator.

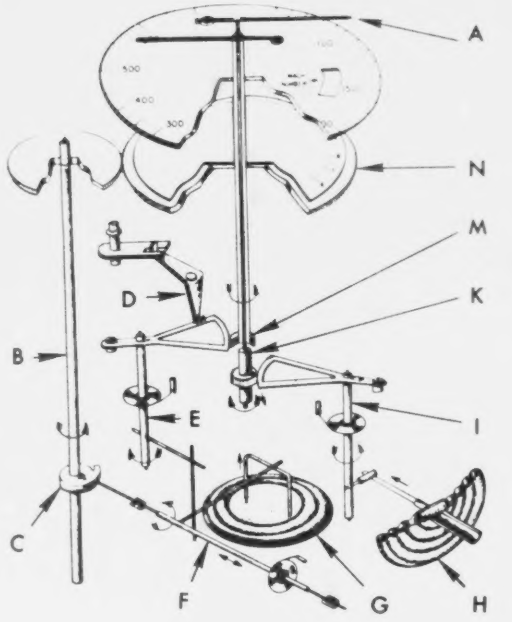
2. Explain how the true-airspeed indicator compensates for temperature changes.

A04. Specify the functions of various components of the maximum-allowable-airspeed indicator.

Maximum-Allowable-Airspeed Indicator. High-speed aircraft reach critical speeds that produce unwanted control problems. They also impose great stress on the aircraft structure. The pilot must know when the aircraft nears this critical speed which decreases in altitude. The pilot must know the flight characteristics of the aircraft and what to expect as airspeed and altitude indications change.

The density of air decreases with an increase in altitude. This causes the speed of sound to decrease. Therefore, the aircraft reaches the sound barrier at lower indicated airspeeds than it does at lower altitudes. The pilot needs a visual means of checking the aircraft's approach to this speed. This need is met by the maximum-allowable airspeed indicator. Here is an example. Suppose that the instrument is redlined for Mach 1.0 (the speed of sound). When the aircraft approaches this speed, the maximum-allowable-airspeed indicator shows this to the pilot. The pilot cannot know that the aircraft speed is close to Mach 1.0 without the maximum-allowable-airspeed indicator. It shows the correct airspeed for a given Mach number setting regardless of changes in altitude.

The maximum-allowable-airspeed indicator has a red barber pole (maximum speed) pointer that operates constantly during flight. The pointer is set to the maximum-allowable-airspeed with the Mach number adjustment. As the aircraft climbs, the barber-pole pointer moves downscale, indicating a descrease in allowable airspeed. Maximum-allowable-airspeed also varies with aircraft design. Therefore, an adjustment is provided from the outside of the case for setting the Mach number and barber-pole pointer.



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A. Indicated-airspeed pointer
B. Shaft and gear assembly
C. Cam
D. Limit lever
E. Sector and rocking shaft assembly
F. Mach rocking shaft
G. Altitude aneroid
H. Airspeed diaphragm
I. Rocking shaft assembly
K. Handstaff pinion
M. Handstaff pinion
N. Subdial

Figure 1-6. Maximum-allowable-airspeed indicator.

The indicated-airspeed pointer is moved by an airspeed mechanism and is driven by a differential pressure diaphragm. The barber-pole pointer is controlled by a sliding lever that is moved by an altitude aneroid.

The mechanism is shown in figure 1-6. Pitot pressure is brought to the inside of the airspeed diaphragm (H) through the pitot pressure line. Pitot pressure causes the diaphragm to expand. This motion is linked to the airspeed rocking shaft assembly (I). The sector gear of the rocking shaft is meshed with the handstaff pinion (K) and the indicated-airspeed pointer (A) is pressed on the handstaff pinion.

Static pressure is brought inside the airtight case through the static pressure lines. As altitude increases, static pressure decreases, and the altitude aneroid (G) expands. This motion is picked up by the lever of the Mach rocking shaft (F) and is transmitted to the sector and rocking shaft assembly (E). The ratio of this motion depends upon the Mach number set into the mechanism.

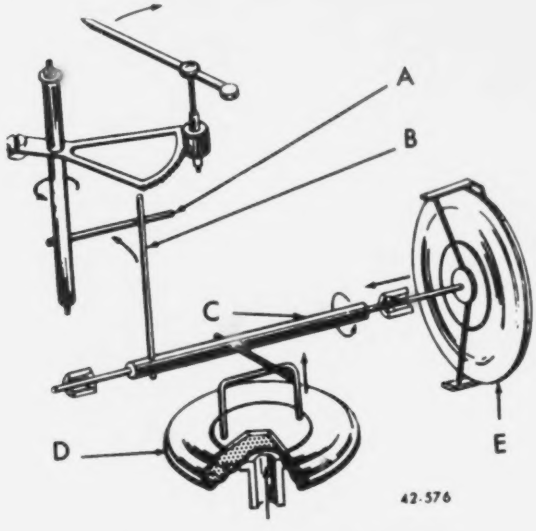
Remember that the Mach number setting is peculiar to the aircraft. Turning the shaft and gear assembly (B) turns the subdial (N). The subdial indicates the critical Mach number. The cam (C) of this assembly moves the rocking shaft, which changes the contact position of the Mach rocking shaft lever with the sector and rocking shaft assembly lever. An increase in the Mach number setting speeds up the motion to the Mach rocking shaft. The sector meshes with the handstaff pinion (M). Turning the adjustment screw at the front of the case moves limit lever (D). The lever controls the backward movement of the sector. This adjustment sets the barber-pole pointer, located below the airspeed pointer (A), to the indicated-airspeed limit of the particular aircraft. When the aircraft operates at speeds above Mach 1.0, we must use a different instrument. This instrument is called the *transonic machmeter.*

Exercises (A04):

1. What is the function of the barber-pole pointer in the maximum-allowable-airspeed indicator?

2. As altitude increases, explain how an indication of allowable-airspeed is obtained?

A05. Name important units of the transonic machmeter.



A. Sector lever
B. Rocking shaft lever
C. Floating shaft
D. Diaphragm
E. Altitude aneroid

Figure 1-7. Operation of a transonic machmeter.

Transonic Machmeter. The transonic Machmeter is used on aircraft capable of approaching or exceeding Mach 1.0. It contains two important units. One is the airspeed diaphragm; the other is the altitude aneroid. The airspeed unit is like those in standard airspeed mechanisms. The sensitive diaphragm expands in proportion to a differential pressure received from the pitot-static system. This is shown in figure 1-7.

The altitude correction mechanism uses an aneroid, which expands when the aircraft goes to higher altitudes. This action changes the multiplying ratio of the mechanism. In this way, the effects of the altitude-density changes are corrected. When aircraft speed increases, pressure inside the diaphragm (D) increases, expanding the diaphragm. When altitude increases, the altitude aneroid (E) expands. This action repositions the floating shaft (C). This movement changes the ratio between the sector lever (A) and the rocking shaft lever (B). At the same time, the sector gear turns the handstaff pinion, which repositions the pointer.

Exercise (A05):

1. Name the two important units of the transonic Machmeter.

A06. Cite the functions and identify the components of the Mach indicator and true-airspeed computer system.

Mach Indicator and True-Airspeed Computer Systems. True-airspeed and Mach number computer systems are used on some aircraft. These systems provide a constant indication of aircraft speed in terms of indicated airspeed, true airspeed, and Mach number. They do this by combining the functions of various units. The effects of altitude, temperature, and pressure are compensated for in the computer. The compensation automatically removes the need for aircrew members to use slide-rule computers, reducing the chance of human error in navigation.

Let's look at the computer system. It includes the true-airspeed indicator, machmeter, and the computer itself. The system uses the same principles as the simple airspeed indicating system, but is more complicated.

Indicator. The master indicator is a P-1 or ME-1. These instruments appear in various sizes, but they all serve the same purpose. The unit shows indicated airspeed, true airspeed, and Mach number. It contains a differential-pressure mechanism, which is connected to the aircraft pitot-static system. It drives a pointer over a fixed dial to show indicated airspeed. A subdial is rotated by a signal from the computer. When the computer receives a static pressure indication, the subdial is positioned so that the indication of Mach can be read against the indicated-airspeed pointer.

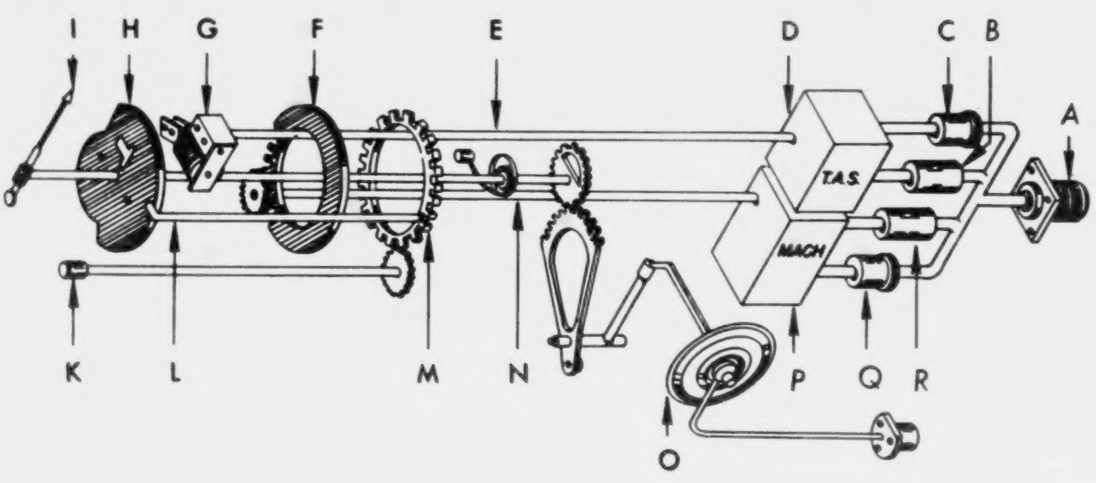


Figure 1-8. Operation of a P-1 or ME-1 indicator.

A. Connector
B. Followup synchro
C. True-aispeed drive induction motor
D. True-airspeed gearbox
E. Counterdrive shaft
F. Mach dial
G. Counter assembly
H. Airspeed dial
I. Indicated-airspeed pointer

K. Set index knob
L. Index marker
M. Index marker gear
N. Mach dial drive shaft
O. Diaphragm
P. Mach gearbox
Q. Mach drive induction motor
R. Followup synchro

Mach number values change with indicated airspeed and altitude. True airspeed is supplied by a countermechanism which is motor-driven. Its indications are read through a window labeled "TRUE" on the face of the dial. Figure 1-8 is a schematic of the master indictor. Pitot pressure operates diaphragm (O). The diaphragm drives the indicated-airspeed pointer (I). Electrical signals enter connector (A). They are sent to the true-airspeed drive induction motor (C) and the Mach drive induction motor (Q). The followup synchros (B and R) are shown beside the motors. True-airspeed gearbox (D) turns counter drive shaft (E). The drive shaft actuates the counter assembly (G), which is viewed through the window in the airspeed dial (H). The SET INDEX knob (K) turns the index marker gear (M), which moves index marker (L) to the reference position. Mach gearbox (P) turns Mach dial drive shaft (N). This action moves Mach dial (F). True-airspeed and Mach number signals come from the C-2 computer.

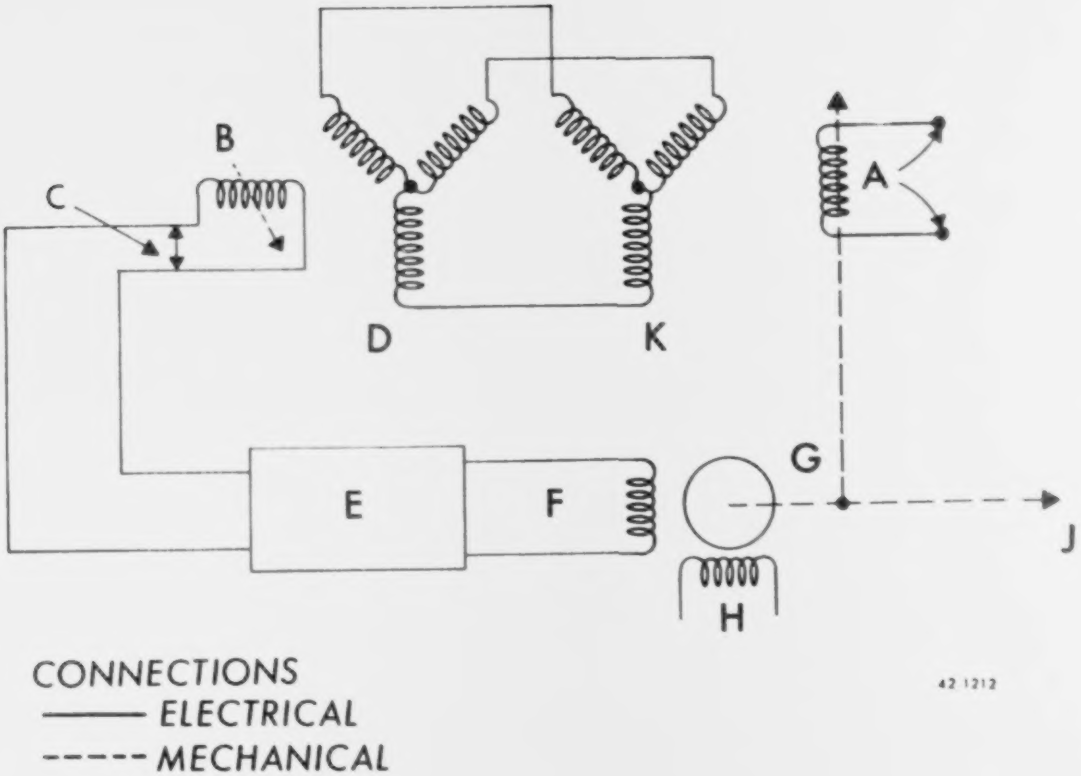
C-2 Computer. This unit uses outside air temperatures and pitot-static system pressures to generate signals that indicate Mach number and true airspeed. This computer is the heart of the system. We will explain how the signals are generated and follow the individual signals through the pickups before they reach the indicating mechanisms.

The major parts of the computer are the gear train housing, the differential pickup, and the static-pressure pickup contained in a shock-mounted case cover on a separate rack.

The differential and static-pressure pickups are housed in the computer in separate cases like those of the airspeed and altimeter mechanisms. The flanged case is flush-mounted to a pickup called the *Synchrotel.* As pitot-static pressures vary, diaphragm or aneroid movements position the rotor of the Synchrotel. The Synchrotel generates the electrical signal that offsets balanced voltages (NULL position) within the computer. The computer channel operates to move the particular system. In the differential diaphragm pickup, the transmitting synchro (Synchrotel) rotor turns as the result of pitot-static pressures. In the static pressure (aneroid) pickup, the rotor turns as the result of static pressure only. A sensitive element (flush-type resistance bulb) measures temperature. The bulb is exposed to airflow and responds to rapid temperature changes. The computer compensates for pressure, altitude, and temperature to indicate Mach number and true airspeed.

Figure 1-9 is a schematic of a servoloop. It is used with the differential and the static-pressure input motions (B). Remember that these motions result from the expansion and contraction of pressure-sensing elements.

Notice in figure 1-9 how the 3-phase windings of the followup synchro (K) are connected to the Synchrotel (D). The rotors are in the same electrical position. The voltage between all phases of each stator is the same (NULL position). If there is no unbalanced voltage, the servosystem is balanced. If the rotor of the Synchrotel is turned to a new position, the servosystem becomes un-



A. AC input
B. Static-pressure input motions (Mach linkage)
C. Error signal
D. Synchrotel
E. Amplifier
F. Variable-control voltage phase
G. Two-phase induction motor
H. Fixed-phase voltage
J. Output motion (Mach linkage)
K. Followup synchro

Figure 1-9. Differential pressure servoloop.

balanced. As a result of this unbalanced condition, a voltage (error signal) (C) is induced in the single-phase winding of the rotor of the Synchrotel.

When the error signal is too weak, it must be amplified to be effective. The amplifier (E) does this. The amplified signal is applied to the variable-control voltage phase (F) of the 2-phase induction motor (G). The fixed-phase signal comes in through the other winding (H). When the variable phase is energized, the motor runs until the error is reduced to zero by the followup synchro. The synchro is driven by the motor through the drive shaft. Whenever there is diaphragm or aneroid movement, an error appears in the servoloop system. The rotor of the induction motor drives the rotor of the followup synchro to the same electrical position as the Synchrotel rotor. This action reduces the error signal at input (A) to null or zero, and the servoloop is balanced again. But how is the signal sent to the respective indicator? Look at the output motor (J). As the induction motor drives the followup synchro, it also drives the machmeter subdial and the counter of the true-airspeed indicator.

The third element is the temperature bridge. The bridge and the third servosystem operate differently. Figure 1-10 is a schematic of this loop. Notice that a Wheatstone birdge servosystem is used with a temperature (electrical resistance) bulb. The bridge is balanced when the voltage drops across legs AB and BC are equal. There is no voltage difference across AC. Notice that the resistance of the temperature bulb is in parallel with resistor E. If the bridge is balanced, a change in the bulb resistance creates a voltage across AB and unbalances the bridge. This voltage is the error signal, which is amplified and applied to the variable-phase winding of the induction motor. The motor runs and moves resistor R1 to balance the bridge again.

Figure 1-11 is a layout of the computer system. Notice that the sensitive pickups (static pressure A, differential pressure F, and temperature G) are the heart of the system. They furnish the initial signals. When the signals are amplified, they drive the gears and differentials. Failure of any one of the sensors affects system operation. Their response to pressure or to temperature change produces the electrical signal in the Synchrotel

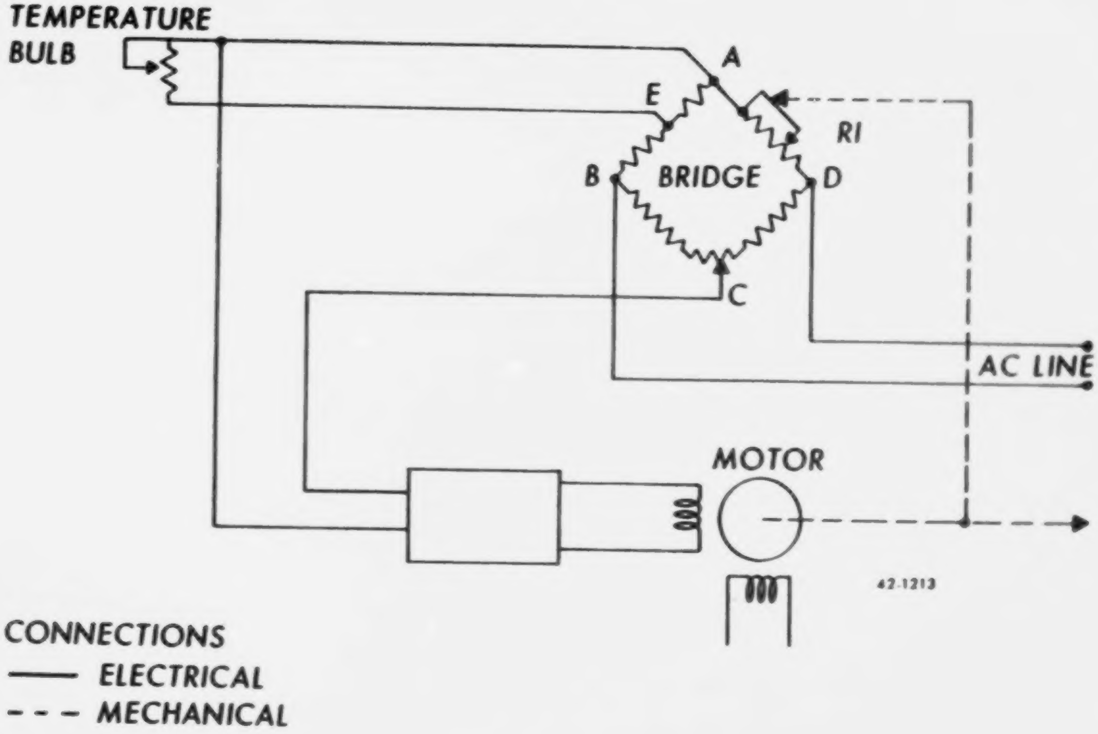


Figure 1-10. Temperature bridge servoloop.

and servoloop system. Inputs from the pitot-static system and temperature servosystem originate the mechanical movement. These movements set up problems that are solved by the computer.

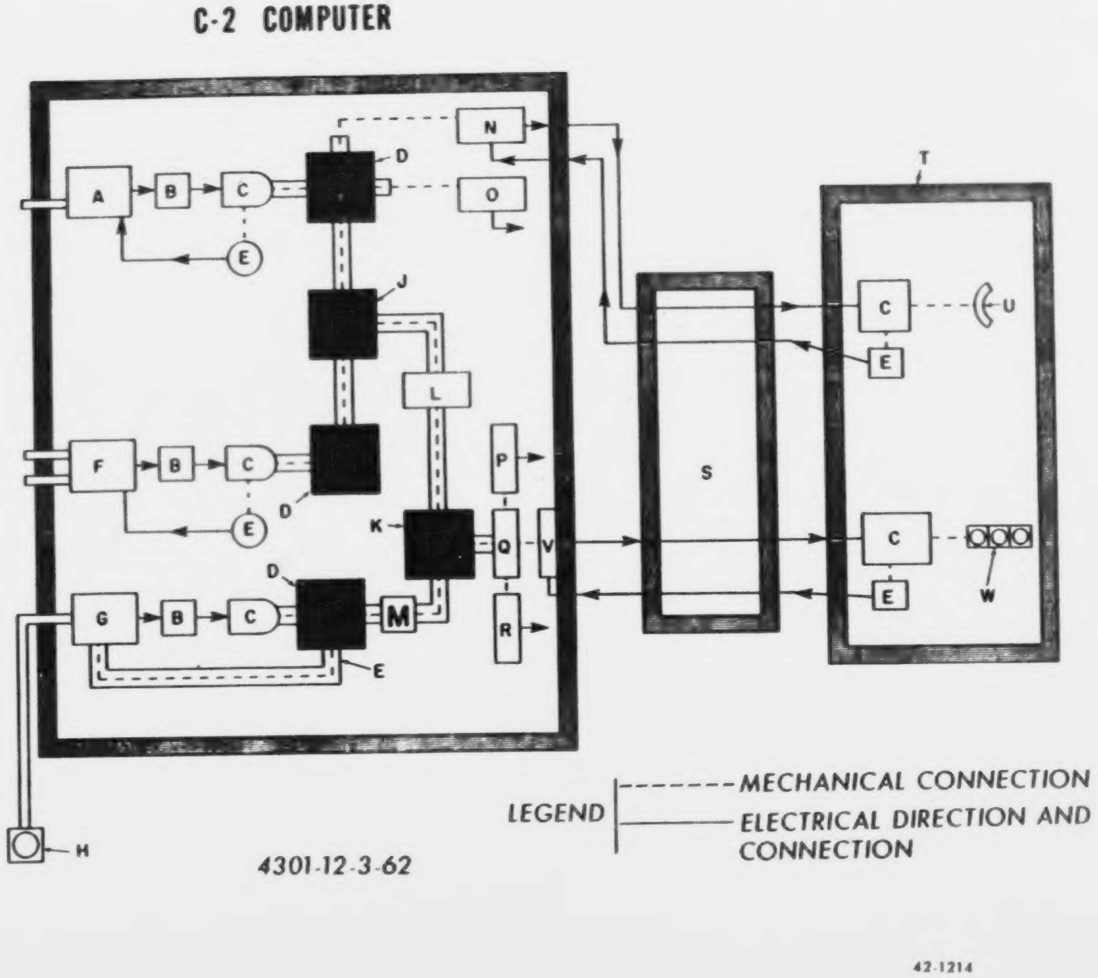
There are servoamplifiers (B) in the computer, along with the powerpack. Two amplifiers boost differential and static error signals. The signals are boosted to values usable by the servomotors (C) and synchros (E). The third element amplifies signals from the Wheatstone bridge. The powerpack transforms the input voltage (115 volts) to the required levels and supplies voltage to the fixed phase of the induction motors. It also supplies followup synchro and amplifier voltage and voltage for the Teletorque (synchro) units in the repeater system.

We have discussed how and why the variable inputs of each servosystem are picked up. You should know how they are fed through the system into the gear trains (D) and how the differentials are located in the computer. Look closely at figure 1-11. Notice that the outputs of the gear trains are combined and transmitted to the various synchros (N, O, P, and R). The synchros change the mechanical signals into electrical signals and send them to the MA-1 amplifier (S). The MA-1 amplifier boosts the strength of the signals and sends them to indicators that show the Mach number (U) and true-airspeed digital counter (W). The indicators are part of the master indicator (T). If another master indicator is needed, another amplifier must be added to the system.

The mechanical differentials respond (position the mechanical gear) to the changes in both differential and static pressures. The effect of cam (L) is predetermined. The cam is arranged so that the movement of the follower shaft going to the output differential is proportional to the difference between the pitot and static pressures, divided by the static pressures. The static-pressure gear train has three mechanical output shafts. One blends its output with the output due to differential pressure. One is connected to transmitting synchro (N), which sends an electrical signal to rotate the Mach-number dial in the master indicator (T). The third shaft connects to the transmitting synchro (O) for the Mach repeaters.

The temperature bridge assembly also has a cam action (M). When the shaft input to the final differential stage is moved, the rotation blends temperature compensation into the airspeed reading. This reading is picked up by the true-airspeed gear train (Q). The gear train sends the signal to the synchros (P, V, and R). A second shaft is also driven through this gear train. This shaft moves the wiper of the Wheatstone bridge. The wiper compensates for temperature change at the bulb (H).

Thus the cams, gear trains, and differentials compute true airspeed and Mach from three input signals. These readings are sent electrically to the master indicator counter and Mach dial. The final motiona comes from the last stage of the gear differentials. The motion


C-2 COMPUTER
N
D
A
B
C
O
E
J
L
F
B
C
P
D
E
K
Q
V
S
T
C
U
E
C
W
E
D
G
B
C
M
R
E
H
LEGEND
MECHANICAL CONNECTION
ELECTRICAL DIRECTION AND CONNECTION
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A. Altitude pickup
B. Servoamplifiers
C. Servomotors
D. Gear trains
E. Synchros
F. Differential pressure pickup
G. Temperature pickup
H. Temperature bulb
J. Differential
K. Differential
L. Cam

M. Cam
N. Transmitting synchro
O. Transmitting synchro
P. Transmitting synchro
Q. True-airspeed gear train
R. Transmitting synchro
S. MA-1 amplifier
T. Master indicator
U. Mach number
V. Transmitting synchro
W. True-airspeed digital counter

Figure 1-11. Block diagram of a C-2 computer.

moves the synchro rotors, which transmit the signal to the indicators. The indicators show true airspeed and Mach number. The Teletorque synchros for the repeaters are driven mechanically and are used like the original signal pickup in the servo Synchrotel. All repeater indicators of the system are connected electrically to the Teletorque transmitting synchro.

The computer contains differentials and gearing that still depend upon basic sensing elements to receive pressure and temperature signals. After computation, the resultant signals are sent to the indicators.

Exercises (A06):

1. In what terms do machmeter computer systems provide airspeed indications?

2. What does the true-airspeed indicator mechanism have in common with the machmeter indicator mechanism of the Mach number computer system?

3. Name the major components of the C-2 computer.

4. Referring to figure 1-11, name the three sensitive pickups used in the C-2 computer system.

5. What changes must be made in the C-2 computer to accommodate another master indicator?

A07. State the purpose and operating principles of the barometric altimeter and determine different pressures and means for adjusting the altimeter to compensate for them.

Altimeter. The altimeter indicates the altitude at which an aircraft is flying by measuring atmospheric pressure. The dial is graduated in feet of altitude instead of in units of pressure. There are two indications on the altimeter. The first is a barometric scale that shows a pressure expressed in inches of mercury (Hg). The second indication is presented by three pointers. They give the altitude in feet. This is the only indication affected by atmospheric pressure change because the change acts on the aneroid. Therefore, altitude is the only indication that changes as the aircraft climbs or descends.

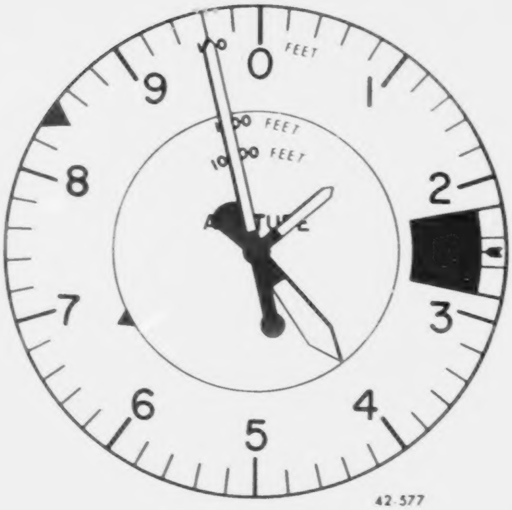


Figure 1-12. Reading the altimeter.

The three hands are mounted concentrically. In figure 1-12, notice that they indicate altitude in feet on a common scale. The longest hand indicates hundreds of feet. It makes 35 revolutions in moving through the range of 35,000 feet of altitude, and 50 revolutions in 50,000 feet of altitude. The intermediate hand indicates thousands of feet. It makes 3.5 revolutions for 35,000 feet of altitude, and 5 revolutions for 50,000 feet of altitude. The shortest hand indicates ten thousands of feet. How many revolutions does this hand make for each of the above indications? Your answers should be 0.35 and 0.50, respectively.

Barometric pressure changes constantly. A means of correcting for these changes is incorporated in the instrument. By turning the setting knob (see A of fig. 1-13), the barometric scale (C) can be set to existing

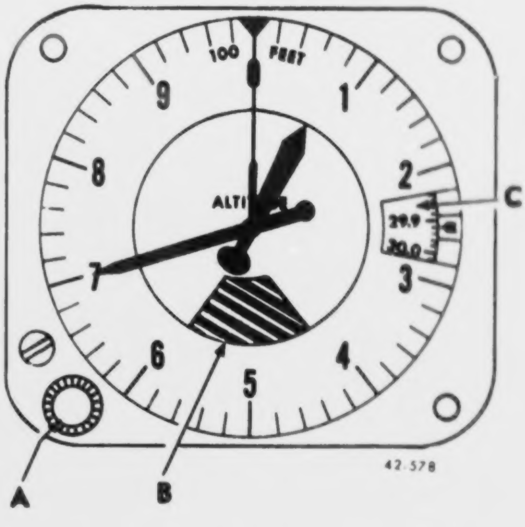


Figure 1-13. Setting the barometric scale.

pressure. The barber-pole (striped) section (item B in fig. 1-13) indicates to the pilot when 16,000 feet is exceeded. The barometric setting is obtained from the weather station. Turning the knob turns the mechanism inside the case to move the scale. When the new pressure in inches of Hg is set, the hands move to the correct equivalent feet of altitude. The relationship is based on the standard atmosphere. The standard atmosphere establishes standard conditions of pressure for each height above sea level.

We have mentioned "standard" atmosphere. The question, "Does it exist in nature?" should be answered "No." The odds are against it. Atmospheric pressure and temperature are always changing. To avoid confusion, a fixed standard for reference was needed. So an average sea level pressure and temperature were defined. Variations of pressure and temperature with height were mathematically calculated and became the standard atmosphere. Standard atmosphere is used in altimetry, engine and aircraft performance charts, and engineering. This type of atmosphere is theoretical and is different from actual atmospheric conditions. The adjustments on the altimeter relate this fictitious atmosphere to actual conditions.

Altimeter operation. To explain the use of the altimeter, you must know certain terms. These terms are (1) pressures altitude, (2) altimeter setting, and (3) sea level. *Pressure altitude* is the height at which existing atmospheric pressure would occur in the standard atmosphere. *Altimeter setting* is a pressure in Hg. It is the existing station pressure corrected to sea level. *Sea level* is the standard from which we measure altitude and pressure. Sea level pressure in the standard atmosphere is equal to 29.92 Hg at 15° Celsius (Centigrade).

Constant pressures do not occur at the heights prescribed in the standard atmosphere. They will be different because of variations in actual atmospheric pressure. The difference in height between points where pressures *should* occur (in the standard atmosphere) and where they *do* occur (at the time they were observed) is called *pressure altitude variation*.

Field elevation pressure is the existing pressure in Hg at 10 feet above the mean (average) elevation of the runway. The altimeter is in the cockpit, and we assume that the cockpit is 10 feet above the runway. Figure 1-14 shows the internal workings of the altimeter. The heart of the altimeter is the aneroid (F). The aneroid is evacuated and sealed, and the case of the altimeter is airtight. Static pressure from the aircraft static system is fed inside the case at (E). The altimeter operates as an aneroid barometer. The main dial (D) is graduated in feet of altitude. At higher pressures, the aneroid is compressed by the external pressure. Higher pressures occur when the aircraft is on the ground. As the aircraft climbs, the surrounding pressure decreases and the aneroid expands. The movement of the aneroid is small, but the mechanism multiplies this movement and causes the large pointer (A) to make 10 revolutions for a change of 10,000 feet in pressure altitude. The intermediate pointer (B) makes one revolution. The small pointer (C) makes one-tenth of a revolution to indicate a change of 10,000 feet in pressure altitude above a known reference. This reference may be sea level or the local field elevation.

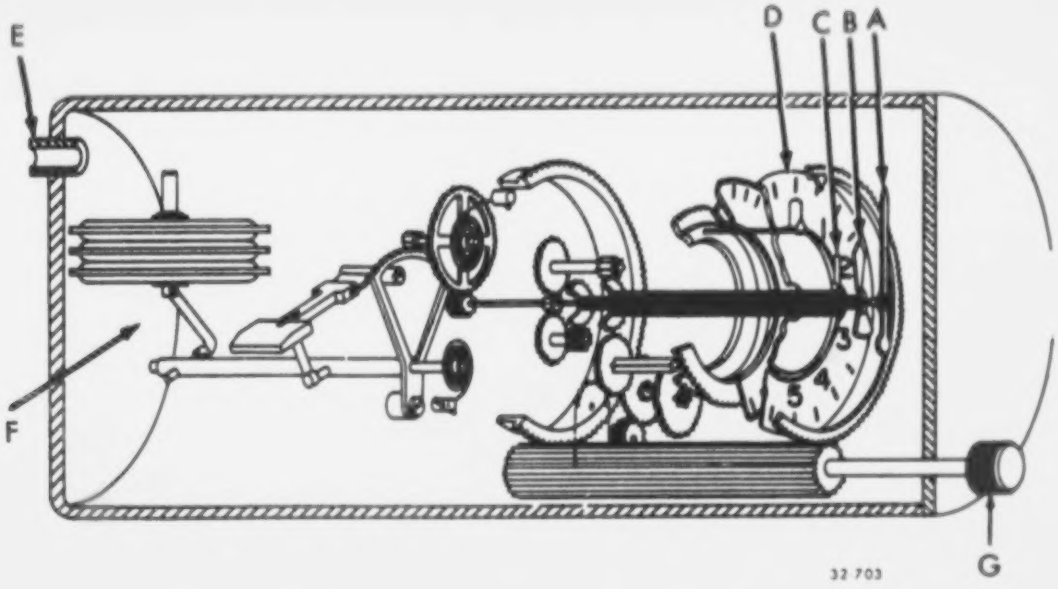
Here is an illustration of altimeter operation. Assume that the instrument is at sea level on a standard day (29.92 Hg). By using the setting knob (G), the three pointers are set to zero. The barometric scale indicates 29.92 Hg. The altimeter is designed so that when the pointers are on zero, the barometric scale indicates the pressure around the instrument. If the altimeter is raised 1000 feet, the pointers will show 1000 feet (assuming standard atmospheric conditions). The barometric scale does not move. The scale setting is not affected by pressure change. The pointers are indicating the actual surveyed elevation above sea level. This is also the pressure altitude. We assumed a standard day (which is the only time when pressure altitude and surveyed elevation are equal). Let's keep the altimeter at this altitude and assume that the atmospheric pressure changes so that the pointers indicate 800 feet. This reading is the new pressure altitude. The difference of 200 feet from the surveyed elevation is the *pressure altitude variation*.

To compensate for this pressure change and have the altimeter read the correct height, you must get a new *altimeter setting*. The local weather station will give you this. If the pressure changed at 1000 feet, it changed at sea level. When you get the new setting, set it into the altimeter barometric scale. In this case, it is 30.14 Hg. Turn the setting knob to change the barometric scale from 29.92 to 30.14. Remember that 29.92 was the *old* setting. The pointers will again read 1000 feet. This is the correct elevation.

The pointers of the altimeter always show its height above a given reference. The altimeter is a pressure instrument. In flight, therefore, the pointers show the height above the level where the pressure on the barometric scale exists.

You must remember one fact. The altimeter is built to show height according to pressure changes set down in the standard atmosphere. These conditions hardly ever exist in nature. Therefore, the altimeter never indicates true altitude except at the level when the actual barometric pressure is observed and the altimeter setting calculated. All altimeter settings are calculated on the earth's surface. The altimeter is accurate there. The error between indicated and true altitude is greater as the aircraft climbs. Indicated altitude may be higher or lower than true altitude, depending upon atmospheric conditions. The error can become so great that all aircraft flying above 18,000 feet must set the altimeter to the same setting of 29.92.

Altimeter setting method. This method is used most of the time. The setting is furnished to the pilot several times. These times are (1) prior to takeoff; (2) during flight, below 18,000 feet; and (3) prior to landing. The altimeter setting system coordinates settings between an altimeter on the ground and the one in an aircraft (in flight). Because the barometric pressure constantly changes, changes in the scale setting of the instrument must be made if the correct elevation indication is to be maintained. The station altimeter is kept at the proper elevation. A pilot needing an altimeter setting is given the scale reading immediately so he or she can set the



A. Large pointer (100 feet)
B. Intermediate pointer (1000 feet)
C. Scale pointer (10,000 feet)
D. Main Dial
E. Static inlet
F. Aneroid
G. Setting knob

Figure 1-14. Internal view of an altimeter.

aircraft altimeter to this setting. It will show the height (above sea level) within the limits of the instrument. Under combat conditions, station altimeter or Weather Service information may not be available. Then the altimeter of an aircraft on the ground is set to field elevation, and the scale reading is radioed to the pilot. This setting gives an indicated altitude above sea level.

Zero setting method. The altimeter setting system is universally used. However, if the pilot desires to land with the pointers reading zero rather than the surveyed elevation of the field, he or she may do so. This is done by requesting, by radio, the observed field pressure which is given as a barometric setting not corrected to sea level. When this setting is used, the instrument will read zero altitude upon landing.

Exercises (A07):

1. What is the purpose of the barometric altimeter?

2. How many revolutions will the large pointer of the altimeter make for a change in altitude of 20,000 feet?

3. Define sea level pressure in the standard atmosphere.

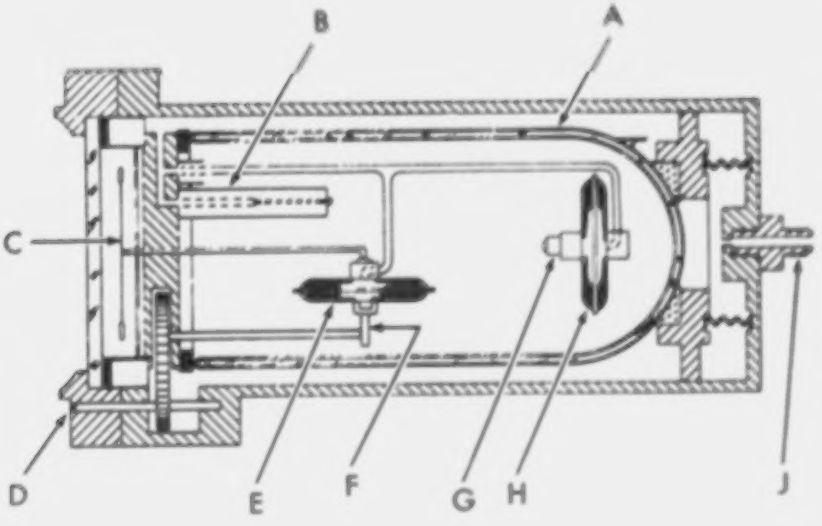
4. What is "pressure altitude variation"?

5. For what purpose is the altimeter designed?

6. At what times is the barometric scale reading usually furnished the pilot?

7. If the pilot uses the zero setting method on the altimeter, what will the pointers read when the aircraft lands?

A08. Explain the purpose and operation of the rate-of-climb indicator.



A. Thermos chamber
B. Diffuser valve
C. Pointer
D. Pointer zeroing screen
E. Diaphragm
F. Eccentric shaft
G. Relief valve
H. Overpressure diaphragm
J. Static connection

Figure 1-15. Internal view of rate-of-climb indicator (with thermos chamber).

Rate-of-Climb Indicator. The rate-of-climb indicator is sometimes called the vertical-velocity or vertical-speed indicator. It indicates the rate at which an aircraft is changing altitude and helps the pilot maintain a definite rate of climb or dive. This indicator shows the rate of ascent or descent in feet per minute. There are two major types of mechanisms used in the instrument. The first type has an internal thermos chamber. The other type has a charcoal container. Both types are used. The indication on both is the same, the they are interchangeable.

Internal thermos type. The internal thermos-type instrument shown in figure 1-15 consists of two principal units: a sensitive differential pressure gage and a thermally insulated air chamber. These units are combined in the case. The mechanism has an extremely sensitive diaphragm unit and a multiplying mechanism. There is a sector gear which meshes with a pinion. A small magnet is pressed onto the pinion staff. When the magnet is rotated, it moves a similar magnet pressed on the handstaff. Motion is transmitted from the sector to the handstaff assembly by magnetic coupling. The need for a pointer shaft extended through an airtight case is eliminated.

Refer again to figure 1-15. Notice that relief valve (G) and overpressure diaphragm (H) prevent excessive pressures from damaging the sensitive capsule. The pointer (C) can be reset to zero by adjusting the eccentric shaft (F) which moves the diaphragm (E) when adjusted by the pointer zeroing screw (D) at the lower left corner of the case. This assembly is housed in the thermos chamber (A). The chamber provides temperature control, which is needed for the following reason. As the temperature within the case changes, the pressure also changes. Pressure from the static connection (J) enters the inside of the diaphragm through an unrestricted opening. Pressure from the same connection enters the thermally insulated air chamber through the diffuser valve (B), which restricts its passage.

In flight, atmospheric pressure decreases as an aircraft ascends (climbs). It increases as the aircraft descends (dives). The rate-of-climb indicator works on this principle. When the aircraft dives, the change of altitude causes an increased static pressure. This pressure enters the diaphragm. The diffuser causes the pressure to enter the case slowly. Thus, the pressure is greater in the diaphragm than in the case. This causes the diaphragm to expand. Expansion moves the pointer in proportion to the pressure difference, indicating the rate of dive. When the aircraft levels off, the pressure in the diaphragm and case equalize, and the pointer returns to zero.

Charcoal chamber type. The charcoal chamber type of instrument mechanism is like the thermos type. Static pressure enters the diaphragm through a dampening valve. The valve controls the rate at which the pressure enters. Static pressure also enters the case (outside the diaphragm) through a temperature-compensated porcelain diffuser valve assembly. Temperature compensation for the air in the case and diaphragm is accomplished by a charcoal container assembly. This assembly has two compartments. One is sealed and contains alcohol and water. The other contains coconut charcoal. The charcoal chamber is connected to the dampening valve and the inside of the diaphragm. There is a valve in the line to the diaphragm that consists of an aluminum plunger in an inner sleeve which is wound with capillary tubing. The valve modifies the flow of air to the chamber and diaphragm. The zero adjustment is made by a slotted shaft in the lower left corner of the mounting flange.

In the charcoal instrument, the charcoal serves the same purpose as the thermos chamber. The charcoal absorbs a large amount of air with decreasing temperature. As the temperature of the instrument is lowered, the air in the case contracts. This reduces pressure, and the diaphragm tends to expand. The charcoal is also being cooled. As the charcoal absorbs more air, it reduces the pressure inside the diaphragm. The reduced pressure causes the diaphragm to contract, canceling the effect of the decreasing pressure on the outside of the diaphragm. The charcoal's rate of absorption increases with a decrease in temperature. As the dampening valve responds to temperature changes, it reduces the effectiveness of compensation at low temperatures. The alcohol-and-water solution compartment delays the rate at which the temperature of the charcoal changes. The alcohol is also the antifreeze for the water.

The pointer on either instrument normally rests on zero. This is the horizontal position in level flight. In a climb, the pointer moves clockwise, or up the scale. When the aircraft is descending, it moves counterclockwise. Pointer stops limit travel to 180° in either direction from the horizontal position. As the mechanism ages, the diaphragm changes position, and the pointer moves off zero. Before each flight, the pointer should be checked for zero position. If it is not on zero, it must be reset with the adjusting screw or the setting knob on the front of the instrument. Lightly tap the instrument while making the zero adjustment. If the pointer does not come back to zero, replace the instrument. If the adjusting screw does not move the pointer from plus 400 to minus 400 feet, replace the instrument.

Exercises (A08):

1. What is the purpose of the small magnet that is pressed onto the pinion staff of the rate-of-climb indicator?

2. What is moved in the rate-of-climb indicator when the eccentric shaft is adjusted?

3. When an aircraft is decreasing altitude, what causes the pressure to go slowly from the diaphragm to the case of the altimeter?

4. What is the purpose of the charcoal chamber assembly in the rate-of-climb indicator?

5. In which direction does the pointer of the rate-of-climb indicator turn when the aircraft is in a climb?

1-2. Errors, Test Equipment, and Maintenance

In this section, we will be discussing altimeter errors, pitot-static test equipment, and correct maintenance procedures.

A09. Name and define the type of altimeter errors and describe a method for reducing temperature error.

Altimeter Errors. The altimeter is calibrated to very close limits, but even so, there are inherent errors. They are called mechanical, hysteresis, temperature, and installation errors. They are discussed in the following paragraphs.

Mechanical errors. Mechanical errors are referred to as *scale error, friction error,* and *position error*. Scale error is determined by comparing the aircraft altimeter with a known correct standard, such as a master (station) altimeter or a barometer. The difference between the indications is the sclae error. Friction error is determined by applying a known absolute pressure to the instrument, then lightly finger-tapping the instrument and noting the pointer indication again. The difference between the readings is friction error. Position error is the change in indications as the instrument is rotated. For example, if the instrument is rotated from a dial vertical to a dial horizontal position, the indications change. This error is caused by a lack of static balance in the mechanism. Tolerances for mechanical errors are listed in the applicable TO.

Hysteresis error. Hysteresis error is the difference between two different indications of the altimeter at one altitude. The first is obtained when the altitude is increased to reach that altitude. The second is obtained when that same indication is approached from a higher point. The second reading is always the highest.

Temperature error. Temperature error in altimeters has been reduced to a negligible amount because of the introduction of a range-compensating fork.

Installation error. Installation error is caused when the static ports sense the wrong static pressure. The slipstream (flow of air around the aircraft) causes disturbances at the static ports. These disturbances cause errors in atmospheric pressure measurements that can be plus or minus errors. They are determined by reference to the performance data section of the applicable aircraft flight manual. Some aircraft have a central air data computer that corrects for this error.

Altimeter setting check. The altimeter setting check is made as follows: obtain the existing setting from the station altimeter. Set the pointers of the meter being tested to read the surveyed elevation of the field; then read the altimeter setting. Check it against the value obtained from the station altimeter. If the two settings do not agree, the altimeter must be reset. Reset the meter according to the procedures outlined in technical orders.

Improvements on the altimeter are continually being made, appearing as modifications of the instrument. One change has been an addition in the form of the striped or "barber-pole" section at the bottom of the dial (see B of fig. 1-13). It warns the pilot when the aircraft is below 16,000 feet. A different 10,000-foot pointer, which is shown in figure 1-13, is the long, inverted type. It improves one's ability to read the dial.

Exercises (A09):

1. What are the four altimeter errors?

2. Define scale error in the altimeter.

3. Define position error in the altimeter.

4. What reduces temperature error in the altimeter.

A10. Describes the test equipment used for checking the pitot-static system.

Test Equipment. Now that we have discussed the parts of the pitot-static system, let's discuss the test equipment used to maintain them. The MB-1 pitot-static tester is used on the flight line for leak and operational checks of the system or components. It is being replaced by the TTU-205 (discussed in Volume 4) which is used in the shop or on the flight line for leak and operational checks of the system and components.

MB-1 pitot-static tester. The MB-1 tester is a manually oeprated portable tester with a hand pressure and vacuum pump. It is used for leak checks and operational checks of the pitot-static system. It uses a regular aircraft airspeed indicator and altimeter for the standards for accuracy. You can see from this that it wouldn't be as accurate as the TTU-205 test set, discussed next.

TTU-205 test set. Remember from the previous discussion that the TTU-205 test set is a portable, hand-carried assembly contained in a combination case. Remember, also, that the static pressure operating range is – 1500 to 80,000 feet, with a tolerance of ± 15 feet or ± .15 percent, whichever is greater. The total (pitot) pressure range is 50 to 1000 knots, with an accuracy of ± 1.5 knots. The rate at which you go from one airspeed or altitude setting can be automatically controlled. This is helpful in checking rate-of-climb indicators.

Exercises (A10):

1. Which of the pitot-static system's testers is manually operated?

2. What feature of the TTU-205 test set is useful in checking rate-of-climb indicators?

A11. Cite reasons and methods for accomplishing pitot-static checks on the aircraft and bench checking components in the shop.

Maintenance Procedures. This objective contains background information that is directly applicable to your job. For instance, you know that you must frequently inspect and perform operational checks on the various parts of the pitot-static system. When something doesn't check out properly, you must do some troubleshooting. Your troubleshooting may indicate a component that you must bench check.

Inspection and operational checks. Inspection and operational checks are frequently performed for faulty operation of the pitot-static system. These inspections include several activities. You must perform a simple check of each heating system to see that it is functioning properly. Check the components for security of mounting, possible cracked cover glass, and improper range markings. Open the drains and check for moisture in the pitot-static lines. You must remember that any time a drain line is opened or an instrument removed for maintenance, a pitot-static leak check must be made.

Troubleshooting the pitot-static system. When you are using the pitot-static tester for troubleshooting, apply pressure or vacuum to the system undergoing test. After you have applied pressure or vacuum to the system, check the reading of the master instrument against the one you are testing. If the instrument is not within tolerance with the master indicator, the entire system should be checked for leaks.

Each aircraft and individual component in the pitot-static system has an allowable leakage. You must refer to the TO covering your particular aircraft for this information.

If leakage is out of tolerance, for example, from the rate-of-climb indicator or a pitot-static line, plug the suspected line. Then apply pressure again and see if the leakage is stopped. If necessary, plug all lines by sections until the leak is located. If the instrument or line is defective, replace it with a serviceable like item. With the system assembled, apply pressure and vacuum to recheck it. If the pitot-static tester shows that leakage is within the allowable tolerance (as given in the applicable TO), you have completed your troubleshooting.

Bench check. For bench checking an instrument, such as the airspeed indicator, you must use the TTU-205 test set. The first test you perform on the airspeed indicator is the leakage test. Make the leakage test by connecting the proper inlet ports to the TTU-205 test set. Apply pressures as specified in the TO. Perform the leak test using the leak test switches on the TTU-205. If the leakage, if any, does not exceed the TO tolerance, the case is considered sufficiently tight. If leakage is excessive, replace the rubber gasket between the flange and the cover glass. If the gasket does not seal when you tighten the cover glass with the holding screws, add two paper gaskets to get the proper seal.

Now you are ready to bench check the airspeed indicator for accuracy. Compare the indicator readings with the TTU-205 readings at the test points specified in the TO.

You may have an airspeed calibration card to fill out at this time. You must follow the instructions given in the applicable TO for the airspeed indicator under test. The preprinted airspeed calibration card also gives the test points in the left-had column. The TO gives the indicator's allowable tolerance.

Before you take each reading from the test indicator, tap it lightly to eliminate any friction error. Record the reading on the calibration card in the column marked "Up Scale." Do this at each test point. Stop at each test point until you have reached the last reading on the test indicator. Record each of these readings as you take them. You are now exactly halfway through the bench check.

Now use the down-scale test points on the calibration card, doing all of the steps in reverse order. Again, before each reading, tap the test indicator lightly to eliminate friction error. Record the readings in the down-scale column. Continue the test point readings until you have reached the last test point. Disconnect the test indicator.

You must now check your calibration and readings against those of the applicable TO tolerances. If all of the readings fall within the TO tolerances, you can put the instrument into supply as a serviceable item. What if the instrument is out of tolerance? The answer to this depends upon your base policy and equipment. If possible, you should repair the instrument as directed by the applicable technical order. If your base policy does not permit this or if you do not have the proper equipment, you must handle it as an NRTS (not reparable this station) item.

Exercises (All):

1. What check is made on the pitot-static system each time an airspeed indicator is removed and replaced?

2. How do you stop a leak in the pitot-static system that is not in an indicator?

3. The leak test of an airspeed indicator is performed before bench checking. How is this test performed?

4. When you are performing a bench check, why should you tap the indictor lightly before each reading?

5. When bench checking an airspeed indicator, how many readings do you take at each test point? What are they?

Electronic Pitot-Static Systems

THIS CHAPTER is in four sections. In the first section, we discuss the Automatic Altitude Reporting System (AIMS); and in the other sections an air data computer system and its inputs and outputs and its maintenance.

2-1. Automatic Altitude Reporting System (AIMS)

In the past 35 years, air traffic has increased at an alarming rate. This increase has caused serious problems in vertical separation of flying aircraft. To overcome these problems, the President's Air Coordinating Committee (PACC) was formed. In 1953, the PACC established the requirements for the air traffic control radar beacon system (ATCRBS).

The ATCRBS consists of an airborne transponder and an interrogator unit on the ground. The military has incorporated the ATCRBS with the IFF (indentification, friend or foe) system. (The IFF system is used during wartime to identify aircraft and to determine if it is friend or foe.) By incorporating these two systems, we have the AIMS designation: A—ATCRBS, I—IFF, M—MARK X11, and S—System.

The AIMS is composed of altimeters, pitot-static sensors, pressure transmitter, altitude computer, and a digitizer. We will be discussing the components and their operation. There are several different altimeters and various computers in use, so we will explain each one separately. First, we will discuss the CPU-46/A computer.

A12. State the purpose and describe the operation of the CPU-46A computer.

Description and operation of the CPU-46A computer. The CPU-46/A computer is a high-altitude computer for supersonic aircraft. Its operating range is from −1000 feet to +80,000 feet. It has a Mach correction factor from .2 to 2.5 Mach. This computer contains total and static-pressure sensors, a computing mechanism, and an electronic package.

The inputs are 115-volt, 400-Hz, total pressure (Pt), and indicated static pressure (psi). The computer corrects for known error characteristics of the static-pressure system for the aircraft for which it was intended. The computer supplies a corrected static-pressure output in the form of an analog synchro output to drive two remote servoed altimeters (type AAU-19/A). It also supplies an encoded U.S. national standard binary code signal to the airborne transponder for altitude reporting. The output of the encoder agrees with the output of the primary synchro to within ±20 feet.

The CPU-46A computer is easily adapted to different types of aircraft. This is done by replacing an easily accessible 2-dimensional, static-pressure detect error correction cam. It also has symmetrically mounted precision aneroids. Thse aneroids minimize errors caused by vibration, acceleration, and position. The aneroids are also mounted in separate pressure chambers so that the computer can be calibrated while it is operating. Along with the above, the computer has a system failure monitoring circuit with a time delay.

Mechanical analog computations are performed from the input information, Two closed servoloop systems provide power for the analog computations. These two systems operate on a null principle to eliminate errors caused by voltage supply variations for normal frequency changes.

A pressure altitude (Hp) shaft positions the rotors of two synchros and a shaft position encoder. The synchro scale factor is 60° per 1000 feet of altitude; therefore, if the pointer moves 360° across the scale, an altitude change of 10,000 feet is indicated. The synchro provides signals for two remotely operated servoed altimeters. The shaft position encoder provides a digital altitude output in 100-foot increments. The alpha-numerical code from the encoder indicates altitude to the transponder. The airborne transponder automatically relays this information in the form of a pulse train to the ground control center upon interrogation. The alphanumerical code is displayed to the ground controller on a radar screen. Aircraft range is determined through measurement of the round trip transit time. Azimuth is determined from the average direction of the main beam of the interrogator antenna when the aircraft transmits its reply.

If a failure occurs, a failure-sensing circuit in the computer removes the power from the AAU-19/A altimeters and opens the common lead to the encoder.

When a failure occurs, a warning light on the pilot's panel illuminates, and a audio tone is heard on the headsets. At the same time, the AAU-19/A altimeters revert to standby mode and operate as a standard barometric altimeter. A time delay in the failure circuit eliminates *nuisance* switching that might be caused by turbulent air or momentary power transients.

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The computer has an externally visible, 10,000-hour, elapsed-time indicator. It displays the total operating time of the computer.

Exercises (A12):

1. The CPU-46/A computer is a(n) __________ computer for __________ aircraft.

2. What is the altitude range of CPU-46A computer?

3. What is the purpose of the CPU-46/A computer?

4. The inputs to the CPU-46/A computer are ______ ______ volts, __________ Hz, __________ pressure; and indicated __________ pressure.

5. How can you make the CPU-46/A computer adaptable to different types of aircraft?

6. What is the reason for using two closed servoloops to provide power for the analog computations?

7. Explain how the ground control center can get altitude information from an aircraft that has an AIMS installed in it.

8. What happens when a power failure occurs in the AIMS?

9. To eliminate errors caused by voltage supply variations and normal frequency changes, the two servoloops operate on the __________ principle.

10. Why is a time delay incorporated in the failure-sensing circuit?

A13. Compare the operation of the CPU-46/A and the CPU-66/A computers, and state the CPU-66/A computer operating principles.

Description and Operation of the CPU-66/A Computer. The CPU-66/A computer is a medium-speed and altitude computer. It has the same inputs and provides the same outputs as the CPU-46/A computer. Its operating range is from −1000 feet to +50,000 feet. It has a Mach error correction mechanism of 0 to .95 Mach. The aircraft static-pressure error is stored on a 2-dimensional, static-pressure error cam. The cam is easily accessible (the same as on the CPU-46/A) in the event a change is necessary, such as when the computer must be calibrated for another type of aircraft.

The physical appearance of the CPU-66/A computer is different from that of the CPU-46/A computer, but the operation is basically the same.

Assume that a small change in static pressure has occured. This will cause the aneroids to expand, rotating the rocking shaft assembly (see fig. 2-1). The rotation causes the *geneva* sector and *locking disc* to rotate the *microsyn* from its null position. Also, a change in the static-pressure correction can rotate the microsyn rotor. In either case, the error voltage generated is amplified and directed to the *2-phase* servomotor.

It drive the *output devices, lead screw,* and *aneroid frame* until the microsyn is again in the null position. Thus, the angular rotation of the frame caused by the aneroid displacement provided a change in the synchros and encoder outputs.

A method of failure sensing is provided in the computer. (It is like the one in the CPU-46/A.) When the failure circuit is actuated, the encoder signal—through the transponder to the ground radar station—is eliminated. The failure system is activated when the servo error signal exceeds a predetermined limit. It also has the built-in time delay *nuisance* circuit.

Two types of sensing devices are used in the computer. The basic uncorrected altitude information is sensed by the pair of aneroids shown in figure 2-1. The aneroid height increases and decreases as external pressure decreases and increases respectively. Links attached to the aneroid transmit the displacement to arms mounted on the rocking shaft, as shown in figure 2-1.

The second type of pressure sensor used in the computer is an airspeed diaphragm. It responds to the difference between total pressure and static pressure. The airspeed diaphragm, also called a *differential pressure capsule,* is shown in figure 2-1. The aircraft total pressure is transmitted into the airspeed diaphragm through tubing leading from the pilot tube. Since the airspeed diaphragm has static pressure acting on its external surface, the diaphragm height increases as the differential pressure increases.

The mechanism can be divided into two separate parts. The first portion is between the pressure sensors and microsyn. Linkages attached to the aneroid capsules provides displacements which rotate the main rocking shaft as a function of uncorrected altitude. The angular displacement of the rocking shaft is approximately 40° for the altitude range from sea level to 50,000 feet. An arm is rigidly attached to the rocking shaft. A geneva sector and locking disc assembly is fastened to the hub of this arm on the rocking shaft by means of a flex pivot. A pinion on the microsyn rotor shaft is driven by the arm on the rocking shaft through the geneva sector and disc assembly with a 10:1 step-up gear ratio. Thus, displacements of the aneroid capsules provide a rotation of the microsyn rotor shaft.

The geneva mechanism is an important feature in the operation of the computer. Its principal purpose is to allow a high degree of sensitivity by multiplying the motion of the rocking shaft by 10 and applying it to the signal generating autosyn. Also, to prevent the possibility of any ambiguous condition from occurring, the motion of the rocking shaft is multiplied by 10 for displacements of ±60° from the null position. For displacements of the rocking shaft greater than 6.0°, the geneva sector pinion does not rotate but is held fixed by the locking disc. Since the nulls on the microsyn are 90° apart and the maximum displacement that can occur under any possible condition of power-on or -off is 60°, the signal to the servo will always be of a proper phase and magnitude to drive the system to null. In normal operation, the geneva pinion and sector remain nulled at the center of the motion transfer. Since the inertia of the system that is reflected to the aneroid is very low, the system can withstand a step pressure input equivalent to full-scale operation without damage to the mechanism.

The differential pressure capsule is used to add altitude correction to basic altitude information. This is shown in figure 2-1. The deflection of the differential pressure capsule is approximately proportional to the log of the difference in pressure. The motion of the frame assembly is approximately proportional to altitude. The Mach computation cam is directly coupled to the frame and rotates as a function of altitude. The link and pin driver-follower mechanisms are designed to compute Mach log $\frac{Pt}{Ps}$ static-pressure error information.

This link rotates the shaft (θ in fig. 2-1) which turns sector and gear assembly to the pressure defect correction cam. The static-pressure error information can then be stored on the static-pressure defect cam as a function of its rotation (Mach number).

The rotation of the static-pressure defect correction cam causes the cam follower arm to rotate about a flex pivot point. As the flex pivot shaft rotates, its angular torque is applied to the rocking shaft arm. This, in turn, rotates the rocking shaft. The rotation causes an angular displacement of the geneva sector and locking disc assembly with respect to the rocking shaft and rocking shaft arm. Since the servomechanism continually repositions the mnicrosyn to a null position, the locking disc assembly and geneva sector are effectively stationary. The displacement is caused by the rotation of the aneroid frame assembly. This, in turn, repositions the output devices. There are two pivotal actions. One is between the pressure defect correction cam follower arm and the rocking shaft arm. The pivot actions allow for limited friction-free angular rotation and backlash by the use of flat, crossed springs.

The second portion of the mechanism is inside the servoloop. The electrical output from the microsyn is amplified and sent to a servomotor-generator unit. The

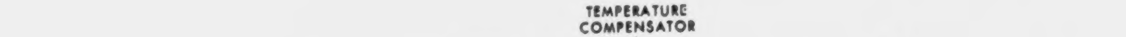
TEMPERATURE COMPENSATOR
CAM-PRESSURE DEFECT CORRECTION
SECTOR
CALIBRATION CAM
AUTOSYN #1
LEAD SCREW
Θ_7
CAM-MACH COMPUTATION
LINK
Θ_3
ANEROID FRAME ASSEMBLY
Θ_5
NUT
PSI
ROCKING SHAFT
Θ_4
FLEX PIVOT
Θ_3
FLEX PIVOT
ANEROID CAPSULES
PT
AUTOSYN #2
GENEVA SECTOR & LOCKING DISC ASSY
Θ_6
MICROSYN
ROCKING SHAFT ARM
DIFFERENTIAL PRESSURE CAPSULE
ENCODER
AMPLIFIER
42-892

Figure 2-1. Computer schematic.

motor drives the mechanism inside the servoloop until the system is back to the null position. This mechanism consists of a speed-reduction gear train, two synchros, an encoder, a lead screw, a nut, a calibration cam, and an aneroid frame assembly. This is shown in figure 2-1. The nut translates rotational movement into a linear movement as it rotates on the lead screw. The nut drives a follower which rotates the aneroid frame assembly, including disc assembly, and microsyn rotor shaft (θ^3). Thus, the electrical output of the microsyn is reduced as the system is driven back to the null position.

The calibration cam allows the aneroid errors, synchro errors, and similar errors to be calibrated out of the system by an adjustment of the servo feedback. The calibration cam consists of a series of segments which are positioned to form a cam-shaped correction profile. The rotation of the nut, due to the profile of the segmented cam, advances or retards the linear motion of the nut due to the pitch of the screw and the slope of a guide surface on the nut. This advancement of retardation is accomplished by the positioning of the segment when the system is energized or pressurized. The cam correction mechanism is in a region separate from the sealed region. The sealed region contains the aneroid and differential pressure capsule. The calibration cam, as presently designed, allows a calibration point for each 1500 feet of altitude. The scale factor of the correction cam can be changed by angling the surface of the nut so that advancement of the nut will cause a displacement of the frame arm greater or less than that due to the pitch of the lead screw. Other devices are used to control accuracy in the servo gear train. These include a hairspring for backlash and an eccentric device for gear center adjustment.

Electrically, the computer contains a single, closed-loop servo consisting of the following electrical components: a rotary signal generator (microsyn), a differential amplifier (output module), a servomotor with a rate generator, a gear train, a power supply, a preamplifier, a failure monitor circuit, and a transformer. See figure 2-1.

The basic electrical operation of the servo begins with an error signal voltage generated at the microsyn. This is caused by a mechanical offset rotation of the microsyn rotor. The error signal is amplified by a simple AC differential amplifier. The amplifier uses bias voltages from a transformer and a solid-state power supply. The amplifier output is supplied to the servomotor, which drives the rate generator and the servo gear train. The encoder and synchro output devices are driven until the original microsyn offset is canceled and the servo is back to the null condition. The rate generator output is coupled back to the amplifier to provide negative feeback for damping and stability.

The failure monitor circuit is designed to keep the failure relay energized only so long as the output of the rotary microsyn remains below a fixed voltage level. The following factors will cause the failure-sensing circuit to indicate a failure: failure of primary power, amplifier, motor, or power transformer; servo followup error; servo gear train seizure or failure; a gross tracking error; or a specific component failure within the power supply. A 3-second time delay is provided by a simple RC network to provent "nuisance" and transient voltages from affecting the relay.

Exercises (A13):

1. What operational difference is there between the CPU-46/A and CPU-66/A computers?

2. State what drives the *output devices, lead screw,* and *aneroid frame* in the CPU-66/A computer.

3. Name the two sensing devices in the CPU-66/A computer.

4. What happens to the airspeed diaphragm in the CPU-66/A computer when differential pressure decreases?

5. In the CPU-66/A computer, what is the angular displacement of the rocking shaft for altitudes from sea level to 50,000 feet?

6. Describe the principal purpose of the geneva mechanism in the CPU-66/A computer.

7. In the CPU-66/A computer, how far can the microsyn shaft move from the null position?

8. Identify the advantage of a low inertia being reflected to the system in the CPU-66/A computer.

9. What are the link and pin driver-follower mechanisms in the CPU-66/A computer designed to do?

10. What do the two pivot actions between the rocking shaft and geneva sector and locking disc assembly, and between the pressure defect correction cam follower arm and the rocking shaft arm allow for in the CPU-66/A computer?

11. State the purpose of the calibration cam in the CPU-66/A computer.

12. How can the scale factor of the correction cam in the CPU-66/A computer be changed?

13. Name the two devices used to control accuracy in the servo gear train in the CPU-66/A computer.

14. What causes an error signal to be generated at the microsyn of the CPU-66/A computer?

15. The failure monitor circuit in the CPU-66/A computer keeps the failure relay energized as long as the rotary microsyn remains below a fixed voltage level. What are some of the reasons that you may get a failure indication?

A14. Identify the purpose of the AAU-19/A altimeter and describe its operating principles.

Description and Operation of the AAU-19/A Altimeter. This altimeter, when coupled to a computer, provides a system designed to meet the requirements for all aircraft and for air traffic control radar beacon systems. This altimeter also provides for automatic standby operation in the event of failure or loss of electrical power.

Description. In the primary mode of operation (servoed), the altimeter accepts an input synchro signal of true pressure altitude from an altitude computer. A servomechanism positions the dial display and control transformer to the equivalent altitude indication of the input. If the indicated altitude and synchro inputs are not the same, the servo will drive the pointers to the true position and override the aneroid system (see fig. 2-2).

In the standby mode of operation, the altimeter operates as a standard barometric altimeter (fig. 2-2). In standby, the pressure input is converted to indicated pressure altitude by means of two aneroids and a linkage and gear mechanism. The altimeter automatically reverts to the mechanical standby mode by means of an integral failure-sensing system in the event of a failure. A flag, with the letters "STBY," appears on the dial to indicate the standby mode of operation.

Primary mode of operation. A schematic of the counter-drum-pointer altimeter is shown in figure 2-2. In the primary mode of operation, the control transformer is driven to an angular position corresponding to the transmitting synchro angle. At this position (null), there will be not voltage output to the amplifier. When there is a difference between the transmitter and indicator synchros, a voltage output to the amplifier is developed. The voltage output to the amplifier is proportional to transmitter and receiver positions. The voltage is amplified and drives the torque motor in a direction to decrease the error voltage, thus positioning the dial display at the true altitude position when the control transformer is nulled. The altimeter will remain in this position until the input signal is changed.

When the servosystem is operating, it must override the mechanical system. A difference will result because the indicated static pressure and true altitude are not necessarily the same. The design limit of this difference is ±4500 feet. The power in the servosystem is adequate to position the mechanical system, compensate for the altitude difference, and indicate true altitude.

The amplifier is a solid-state modular circuit which is built into the altimeter. A unique arrangement of the transistors enables it to be used without an output transformer. The major advantages are reduced size and weight and increased gain. In addition, the amplifier contains a failure-sensing circuit. The circuit consists of a relay reset switch and 2-stage transistor amplifier. It is designed so that an energized relay holds a set of contacts in the servo circuit closed during normal powered operation. In the event of a signal to the failure amplifier, the relay will be deenergized and the contacts in the servo circuit will open. The altimeter will revert to standby mechanical operation. It will remain in standby until the pilot switches it back to electrical (reset) operation. In the lower right-hand corner of the bezel is a self-centering control switch. It is designed so that the electrical system will be deenergized when the switch is rotated 30° counterclockwise. The electrical system is engergized when the switch is rotated 30° clockwise from neutral. A signal is sent to the failure amplifier in the event of gear train seizure or servoamplifier or motor failure. The signal causes the last stage of the amplifier to cut off. It thereby deenergizes the relay and reverts the altimeter to standby operation.

While the altimeter is in primary, the STBY flag is held out of view by an electric actuator. The STBY flag is automatically brought into view by a spring when the altimeter is returned to the standby mode.

Standby operation. In standby, the pilot is presented with indicated static pressure altitude instead of corrected pressure altitude. Two large diametrically opposed aneroids react to the indicated static pressure from the static system. The symmetrical arrangement of the aneroids effectively eliminiates errors due to position, acceleration, and vibration. The use of large aneroids reduces the friction and hysteresis errors. A temperature-compensated linkage (bimetal) connects

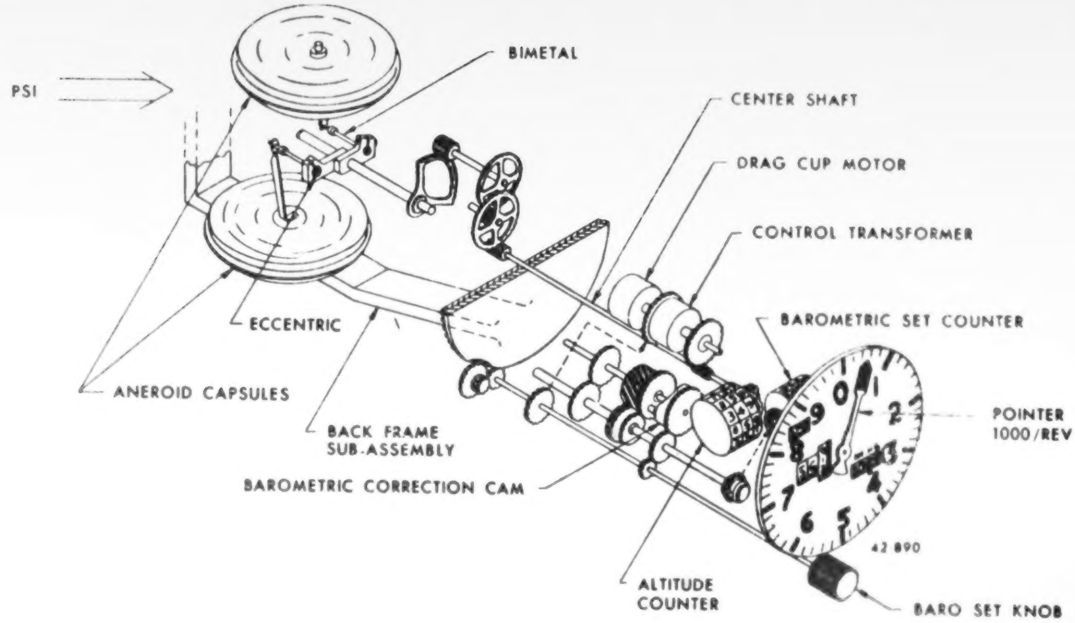

Figure 2-2. Servoed altimeter mechanical schematic.

the aneroids to a common rocking shaft. The motion is mechanically amplified and transferred to the dial indication through precision, jeweled gear stages (see fig. 2-2).

The electrical servosystem is interconnected with the mechanical system. The aneroids must drive the rotating components of the servosystem while the altimeter is in the standby mode. Use of large aneroids provides adequate input power to the mechanical system. The low-inertial drag cup motor and brushless low inertial control transformer minimize the inertial and friction effect on both systems.

Baroset operation. When making the barometric setting, there are one baroset knob and three independent gear trains. Each one is calibrated and locked in the correct relationship and responds to a change in baroset setting under three conditions. First, a nonlinear gear train connects a 4-digit counter to the baroset knob shaft (see fig. 2-2). The counter, graduated in inches of mercury, is prominently visible through a cutout in the dial of the altimeter. Second, a gear train, driven from the baroset control knob, compensates for changes in baroset setting in the servosystem. The fixed stator windings in the control transformer are rotated by a signal from the altitude computer. This corrects the signal to agree with the baroset counter in the altimeter. Third, the mechanical standby system is aligned to the baroset counter indication through a third gear train. The calibrated standby system is rotated to agree with the baroset counter. In rotating the mechanical system, the interconnected rotor of the control transformer is positioned to its correct relationship with the input synchro signal, as explained in the second condition above.

You will find it easy to make a barometric setting on the AIMS altimeter. Use the same procedure that you use to set a standard barometric altimeter. There is one exception—the AIMS altimeter must be brought to room temperature before you make the adjustment.

Exercises (A14):

1. What is the purpose of the AAU-19/A altimeter?

2. In the primary mode, what happens if the indicated altitude and synchro inputs are not the same?

3. What happens when the primary mode of the AAU-19A altimeter fails?

4. When will a voltage output to the amplifier in the AAU-19/A altimeter be developed?

5. What are the major advantages of the solid-state amplifier in the AAU-19/A altimeter?

6. What brings the STBY flag into view when the AAU-19/A altimeter is turned to the standby model?

7. In standby operation of the AAU-19/A altimeter, what does the symmetrical arrangement of the aneroids eliminate?

8. How is the inertial and friction effect minimized in standby and primary operation of the AAU-19/A altimeter?

9. What must be done before you make a barometric setting on an AIMS altimeter?

A15. Cite the AIMS test equipment and specify AIMS maintenance procedures.

Test Equipment. There are two tests sets for testing the AIMS. One is the TTU-205, and the other is the TTU-229/E test set. Since we have already discussed the TTU-205, we will only discuss the TTU-229/E.

The type TTU-229/E is the other piece of test equipment required to check the AIMS. It, too, is a portable tester contained in a combination case. The test set will accept and display encoder and synchro altitude signal outputs from the computer. It monitors signals that normally would have gone directly from the computer to the aircraft transponder and servoed altimeters. The TTU-229 has an ON-OFF lamp that continuously monitors the failure warning circuit in the computer. The test set also has a manual control to enable you to check failure warning capability. There are eight cables supplied with the TTU-229/E test set for interconnecting it to other components. A power cable is also provided for connecting the test set to an external power source.

All controls, displays, receptacles, and indicators are mounted on the control panel. Three of the displays are readout devices which simultaneously display the encoder and synchro altitude from the computer under test. The encoder output is displayed in both binary-coded form and as a decimal readout directly in feet of altitude. The synchro output is displayed as an altimeter-type readout in feet of altitude.

Inspecting. Inspection of the AIMS consists of visually checking the altimeter for tightness of the cover glass and discoloration and deterioration of the instrument. You should also check all the tubing to insure that there are *no* cracks and that it is *not* chaffing (rubbing) against anything.

The computer should be checked to insure that it is mounted securely and that the lines connected to it are tightened securely. The computer should also be checked to insure that *nothing* is chaffing against it.

All the wiring should be checked to insure that it is not chaffing against anything. All connectors should be checked for security and lockwired if required by the applicable aircraft technical order.

Exercises (A15):

1. What test sets are used for testing the AIMS altimeter system?

2. For what do you check when inspecting the AIMS?

A16. State procedures in operationally checking the AIMS and bench checking its components.

Operational checks. Operational check of the AIMS consists of connecting the TTU-205 and TTU-229/E test sets or TTU-205 and IFF transponder test sets in accordance with the applicable aircraft technical order and comparing input altitudes against the indicated altitudes to insure proper operation. It includes a checkout of the installed altimeters with the altimeter switches in STBY (standby) as well as a complete checkout of the altitude computer system. When performing the complete checkout, the IFF transponder must be operated in conjunction with the altitude computer system to verify that the altitude computer is supplying the correct information to the transponder for altitude reporting. In the complete checkout, a NAV-AIDS specialist must connect the transponder test set to the transponder and set the tester up for "Mode C" operation. This is to check for radiation of properly coded altitude information.

The operational check of the AIMS altimeter also includes checking the correct operation of the instrument vibration while in "standby" operation.

Let's go through the operational check of the AIMS, excluding the check of the transponder. To begin with, always remember that the TTU-205 test set is a delicate measuring device. Its use outside in inclement weather is not recommended without some type of shelter from wet conditions, which may cause damage to the tester, present a shock hazard to personnel due to electrical shorting, and result in incorrect readings. Perform the checkout of your test set before connecting it to the AIMS system. Also remember, it must be operating and

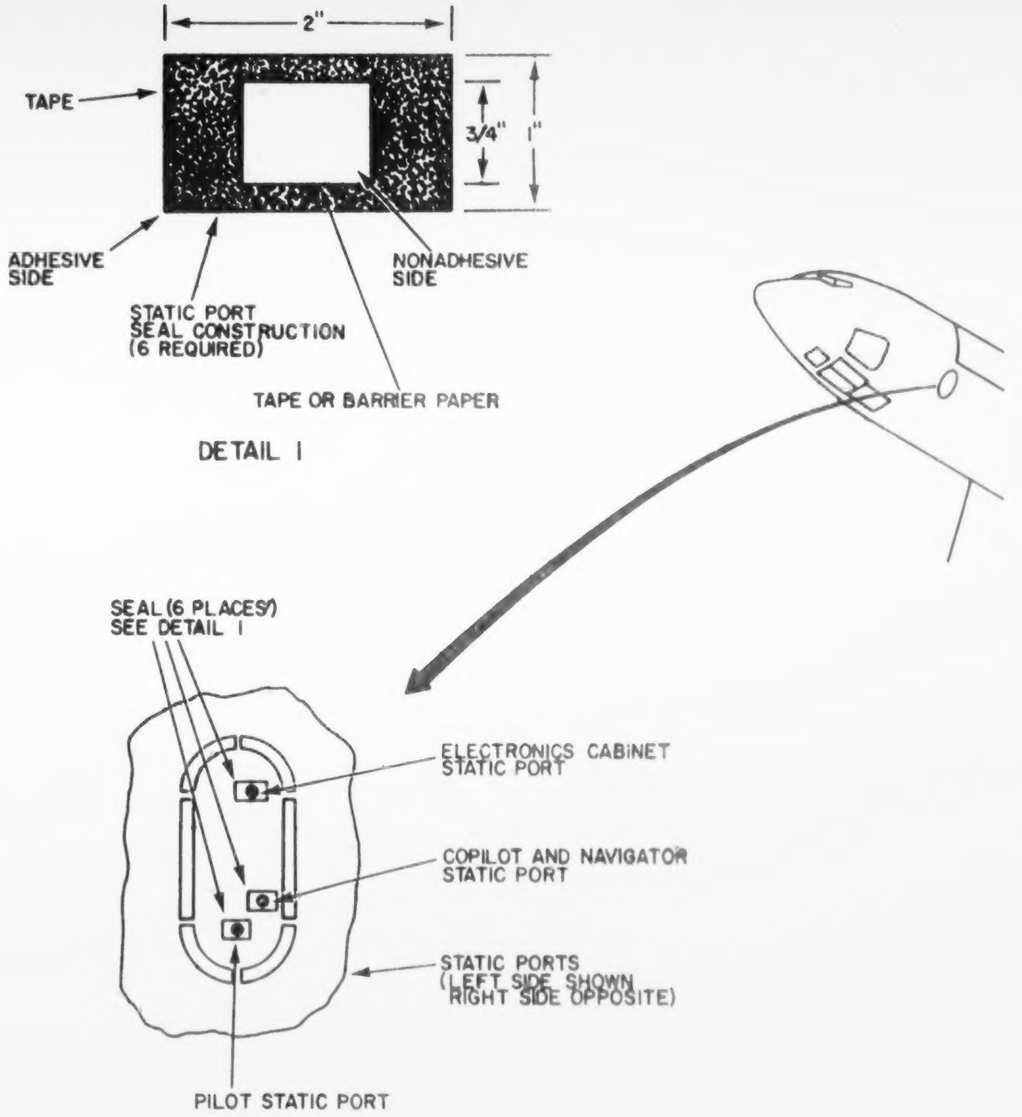
2"
TAPE
3/4"
1"
ADHESIVE SIDE
NONADHESIVE SIDE
STATIC PORT SEAL CONSTRUCTION (6 REQUIRED)
TAPE OR BARRIER PAPER
DETAIL I
SEAL (6 PLACES) SEE DETAIL I
ELECTRONICS CABINET STATIC PORT
COPILOT AND NAVIGATOR STATIC PORT
STATIC PORTS (LEFT SIDE SHOWN RIGHT SIDE OPPOSITE)
PILOT STATIC PORT

Figure 2-3. Static port tape seals.

stabilized at the local field elevation indication before connecting the TTU-205 to the AIMS.

For many types of aircraft, special adapters are available to connect the tester to the aircraft system and seal off the system. However, if such adapters are not available and you must connect the tester to the system through test ports or pitot-static drains, you will have to use tape to seal off the static ports and drain holes in the pitot tube. The tape mastic (sticky surface) should never be in direct contact with the static ports. When the tape is removed, some of the mastic is usually left upon the surface and, if applied directly to the static ports, it could block some of the "salt-shaker" holes. To assure that the tape mastic does not contact those holes and to assure a good seal, use a piece of barrier paper underneath the tape or cut a segment of tape approximately 2 inches long and reverse cover the tape segment with a 3/4-inch square piece of tape so that the tape mastic will totally contact the airplane skin at the edge of the static port only (see fig. 2-3). The tape used to seal the static ports should be a 1-inch minimum width nonporous red cloth tape.

Next, apply pressure to the pitot system at a rate NOT EXCEEDING 100 knots per minute until the counter on the tester indicates the knots setting specified in your TO for the leak check of the system. Hold the airspeed LEAK TEST switch on the TTU-205 to the ON position for one minute. The leak rate tolerance will also be given in the TO; but normally, the airspeed reading on the tester should not drop more than 2 knots in 1 minute. Release the LEAK TEST switch and decrease pitot pressure to 60 knots. Then check the static system for leaks.

Apply vacuum (static) pressure at a rate NOT EXCEEDING 5000 feet per minute until the altitude counter on the TTU-205 reads 10,000 feet. Hold the altitude LEAK TEST switch in the ON position for one minute. The altitude reading on your test set should not decrease at more than the rate per minute specified in the TO. This tolerance varies considerably between different types of aircraft.

After performing the leak check, electrically connect the TTU-229 to the altitude computer and to the AAU-19/A altimeters. Check that all applicable circuit breakers are closed and that the RESET-STBY switch on each altimeter is in RESET. Adjust the altimeter barometric scale to read 29.92. Proceed to each of the altitude and airspeed test points given in your TO. At each test point, note the readings on the TTU-229 for both the pilot and copilot positions if the aircraft has dual controls. Normally, they should agree within 20 feet. On the TTU-229, the ENCODER READOUT lights that are illuminated at each test point should match with the listing given in the TO. Also, the aircraft altimeters should agree with the TTU-229 altitude display within the TO specified tolerance. Switch the altimeters to standby. The altimeter vibrators should operate and each altimeter reading should be within the appropriate acceptable range listed in the TO. Check the STBY and RESET modes at each test point given. Finally, place the altimeter switches in the STBY position and perform the TTU-205 test set run down procedures. Remove the pitot tube closures and the tape from the static ports if used. Disconnect all test equipment and return the system to its normal operating condition.

Before leaving the aircraft, adjust the altimeter's barocounters to ambient barometric pressure corrected to sea level and rotate the RESET-STBY switches to reset position. Record each altimeter reading. Each altimeter should read station altitude ±75 feet. Go back to the STBY mode and record each altimeter reading. Each reading taken in the RESET mode should agree with the reading taken in the STBY mode within 75 feet. Also, each altimeter should agree with the other altimeter(s) within 80 feet.

The barometric counter may be adjusted in STBY (pneumatic) mode when the altitude pointer and barometric counter become unsynchronized. Flight line adjustment in the RESET (servoed) mode is NOT authorized. If excessive error is evident in RESET mode, either the altimeter or the computer may be at fault and proper alignment can be accomplished only by removing the faulty unit from the aircraft system. Adjustment of the AAU-19/A altimeter can be done in the shop.

Bench Checks. Bench checking the altitude computer is basically the same as the flight line checkout procedure. However, in bench checking the AAU-19/A altimeter, the first step is to verify the adjustment of it. If it is out of adjustment, you must ascertain the manufacturer of the altimeter before attempting to adjust it. Use the TTU-205 to obtain zero (0) feet of altitude according to the TTU-205 altitude counter.

Rotate the altimeter barometric set knob to set the altimeter pointer to zero on Aerosonic and Kollsman altimeters. Rotate the barometric set knob on a Bendix altimeter to indicate 29.92 inch Hg. Loosen the barocounter locking mechanism by matching the manufacturer with instructions below:

Aerosonic altimeter—Loosen, but do not remove the locking screw located directly beneath the barometric set knob. This will loosen the knob locking plate.

(2) Kollsman altimeter—Remove the locking screw located to left of barometric set knob; then loosen locking pin located on side of bezel. (On some units, it may be necessary to remove locking pin.)

(3) Bendix altimeter—Loosen (approximately four turns), but do not remove the locking screw located beneath knob. Do not force the screw if resistance is felt the shaft lock, located on bottom of the bezel will drop approximately flush with bottom.

Withdraw the barometric set knob and adjust the barocounter readout to 29.92 inch Hg on the aerosonic and Killsman or altitude printer to read zero feet on the Bendix altimeter. (NOTE: Always make adjustments by rotating the knob in a counterclockwise direction, then approaching the desired setting from a clockwise direction.)

Verify the zero setting by returning knob to normal position. Pointer should still indicate 0 (±5) feet with 29.92 inch Hg indicated on barocounter. If not, reset it.

Lock the barometric set knob by reversing the procedures just given. The rest of the bench check procedure is basically the same as the flightline checkout procedure just discussed. It consists of supplying the pressure inputs using the TTU-229. Complete bench check procedure is beyond the scope of this CDC. For bench check procedure, you should refer to the applicable equipment TO.

Exercises (A16):

1. What test equipment is required to operationally check the AIMS?

2. The complete checkout of the AIMS requires the operation of what associated system?

3. List the things that must be checked during an operational check of the AIMS.

4. What hazard is presented by the TTU-205 during wet weather?

5. What should be the status of the TTU-205 at the time you connect it to the AIMS?

6. What procedure should you use to seal the aircraft static ports if test adapters are not available?

7. What is the maximum rate at which pitot and static pressures should be applied to the AIMS?

8. What barometric setting do you set into an AIMS altimeter for operationally checking it?

9. The TTU-205 tester run down procedure is done with the AIMS altimeter switches in which position?

10. What is the maximum allowable difference between the readings of an AIMS altimeter in RESET and STBY mode at station altitude.

A17. State the test equipment required and identify procedures to follow for troubleshooting the AIMS.

Troubleshooting. When troubleshooting the AIMS altitude computer system, you use the TTU-205 test set to supply pressure inputs to the computer and the TTU-229/E test set to monitor the outputs of the computer. With the test sets connected, you can perform a scale error check, friction error check, or any of the checks we have already discussed. There is one other test set that you use when troubleshooting that we haven't mentioned. kThis piece of equipment is the multimeter. You should check the system wiring before you change a component you suspect as being unserviceable. With the appropriate aircraft wiring diagram and a multimeter, you should be able to check all the wiring between the AIMS components. At this point, we can discuss a few malfunctions and the probable causes. Fist, we will discuss an isolation procedure and how to remedy the problem.

Let's say that there is a malfunction that is causing erratic altimeter operation in standby mode. When we check the altimeter and find that it has excessive friction, we check also to see if the altimeter vibrator is operating. If the vibrator is inoperative or the altimeter is ticking excessively, the altimeter needs to be changed. Also, altimeter scale error could be too high, giving erratic indications. A scale error check should be completed on the altimeter. If all the checks you have just completed are satisfactory, there is probably an intermittent obstruction in the static line. If the line has an obstruction in it, it should be purged in accordance with the applicable aircraft TO.

Let's try another malfunction. Let's say that we have no altimeter indication in standby. A good possibility is a completely clogged static line. If there is evidence of dirt or water in the static line, it should be purged. The trouble could also be an excessive static lead or defective altimeter. When you perform a static pressure check, you can check the static lines for leaks and the altimeter for accuracy at the same time.

Another problem you may encounter is this: the pilot's and copilot's altimeter readings do not agree within tolerance in the standby mode. One cause could be obstructions or leaks in the static line. Lines should be clear and leakproofed. Also, the pilot's or copilot's altimeter could be defective. You can check this by performing a *scale error* check on the altimeters. You already know that if an altimeter is defective, it needs to be changed.

If we had a problem that causes the pilot's and copilot's altimeters to disagree within 80 feet in the primary mode, the most logical solution would be a defective altimeter. First, you should perform a *scale error* check on the altimeters in the primary mode. If either altimeter does not read within 30 feet of test set altitude display, it is unsatisfactory and you need to perform a scale error check on the computer. If the pilot's and copilot's altitude displays on the test set does not agree within ±20 feet, the computer is defective.

Assume that we have this problem: both altimeter readings agree with each other. but they are out of tolerance with the test point altitude. If the readings were low, a good possibility would be an obstruction or leaking static line to the computer. If the readings were high, then the computer would be defective. This should be enough problems to give a general understanding of what a certain defect will cause. The quickest and most positive way to approach a problem is to think about the most logical component that will cause the problem. Check the components with the proper test equipment. If all the components check out as serviceable, then you can be quite sure there is a wiring problem. With a multimeter and the correct wiring diagram, it shouldn't take you long to locate the problem and correct it.

Exercises (A17):

1. What test equipment is required to troubleshoot the AIMS?

2. Explain what you would do if the pilot's and copilot's altimeters do not agree within 80 feet and both altimeters bench check good.

3. What would be the most probable cause of a low indication on both altimeters?

2-2. Central Air Data Computer System (CADC)

Even in the early days of manned flight, a limited amount of air data was required by pilots. A silk streamer attached to a strut or wire provided information regarding airflow conditions around the point of attachment. Velocity was approximated by engine speed or by the force of wind on exposed portions of the pilot's face. Altitude determination was dependent upon the pilot's depth perception.

As time went on, aircraft were designed to fly at much higher speeds and altitudes. This resulted in a need for more accurate instrumentation.

Altimeters and airspeed indicators were designed and improved through the years, but with today's sophisticated, supersonic aircraft, a need for continuous air data information with high accuracy is required.

The effectiveness of our high performance aircraft is dependent upon the accuracy and speed with which the air environment can be measured and the information transmitted to the various aircraft systems which require this information. The environment information that we will discuss are the three raw inputs to the air data computer. These three measurable inputs are static pressure, total pressure, and temperature.

NOTE: There are different types of central air data computers, but to discuss them all is beyond the scope of the CDC; so we will only discuss one. If it is not the CADC used on your assigned aircraft, try to relate its function and operation to the CADC that is.

When discussing the operation of the central air data computer system, common terminology has come into use which describes the measuring and computing functions of the system. In this section, we will be defining these terms.

A18. Define indicated and true airspeed.

Indicated Airspeed. Indicated airspeed is the apparent speed of an aircraft in reference to ambient air which is expressed in mph (miles per hour) or knots (nautical miles per hour), and is derived from the impact pressure of the air at ambient density and temperature as sensed at the pitot tube and flush static ports.

Indicated airspeed is a function of pitot-static pressure differential or impact pressure (Qc). Indicated airspeed, neglecting instrument errors, is identical to true airspeed at sea level on a standard day. Any increase in altitude will normally cause the indicator to read a value lower than the true airspeed as a function of density.

True Airspeed. True airspeed is the actual speed (velocity) of an aircraft in reference to ambient air, expressed in mph or knots. In this CADC, true airspeed is computed from a relation of Mach number to total temperature.

True airspeed should not be confused with groundspeed, as air movement (wind) relative to the ground will change the groundspeed as related to true airspeed.

Exercises (A18):

1. Define indicated airspeed.

2. Define true airspeed.

A19. Describe three different type bellows used in the CADC.

Aneroid Bellows. This is a bellows that contains no liquid. The term aneroid bellows has been vastly misused. By common definition, an aneroid bellows is a bellows which has essentially a pressure of 3 to 5 microns on the inside. Misconceptions have stemmed from the used of such a bellows in an aneroid barometer, and people have assumed that every evacuated bellows must be an aneroid bellows.

Evacuated Bellows. This is a bellows which contains a pressure less than atmospheric at sea level (29.92" Hg A). To determine the specific pressure inside an evacuated bellows, the blueprint for the applicable part number should be consulted. Some evacuated bellows are partially filled with oil to minimize work hardening and cracking.

Differential Bellows. This is a nonevacuated, vented bellows used to sense a pressure differential by application of pressures on the inside as well as the outside of the assembly. The resultant of the two forces will be felt in both direction and magnitude.

Exercises (A19):

1. Describe an aneroid bellows.

2. Describe an evacuated bellows.

3. Describe a differential bellows.

A20. Define the terms "absolute pressure, altitude pressure, and impact pressure (Qc).

Absolute Pressure. Absolute pressure is a pressure measured in reference to a complete vacuum (0 Hg A). It is distinguished from gauge pressure by suffixing "A" to the indicated pressure (Hg A or psia).

Altitude Pressure. This is a pressure equal to barometric pressure (absolute) at the stated altitude. For example, a 10,000-foot pressure altitude is equivalent to 20.58 Hg A. Regardless of its actual location, 20.58 Hg A is the pressure at 10,000 feet in a standard atmosphere.

Impact Pressure (Qc). The pressure increases above ambient exerted by air on the leading surfaces of an aircraft is a function of its indicated airspeed is defined as impact pressure. Impact pressure is the difference between static and total pressure as sensed by the flush ports and pitot tube respectively.

Exercises (A20):

1. Define "absolute pressure."

2. Define "altitude pressure."

3. Define "impact pressure."

A21. Describe indicated static pressure (Psi) and total pressure (Pt).

Indicated Static Pressure (Psi). Indicated static pressure is the atmospheric pressure as sensed in the flush ports located in the aircraft skin. Static pressure values sensed at the flush ports are fairly accurate in the subsonic speed ranges. Shock waves and local airflow disturbances in the transonic and/or supersonic ranges cause erroneous pressure values to be sensed. The magnitude of this error is usually given as the ratio of static pressure to indicated static pressure, as related to Mach number.

Total Pressure (Pt). This is the total air pressure present at the leading surfaces of the aircraft in flight. Total pressure is the sum of static and impact pressures. Total pressure is sensed in a pitot tube somewhere on a leading surface of the aircraft.

Exercises (A21):

1. Describe indicated static pressure (Psi).

2. Describe total pressure (Pt).

A22. Define the terms "static temperature (Ts)" and "total temperature (Tt)."

Static Temperature (Ts). Static temperature is the temperature of the air through which the aircraft is flying (ambient air temperature).

Atmospheric temperature normally changes 3.0° F. for each 1000 feet of altitude change. It decreases with altitude until a constant value of −69.7° F. or −56.5° C. is reached at an altitude of approximately 37,500 feet on a standard day. This constant temperature value is considered to prevail to an altitude of approximately 82,000 feet.

Total Temperature (Tt). This is the temperature of the static ambient air plus the compression temperature rise of the air due to the velocity of a moving object (ram temperature rise).

Exercises (A22):

1. Define "static temperature (Ts)."

2. Define "total temperature (Tt)."

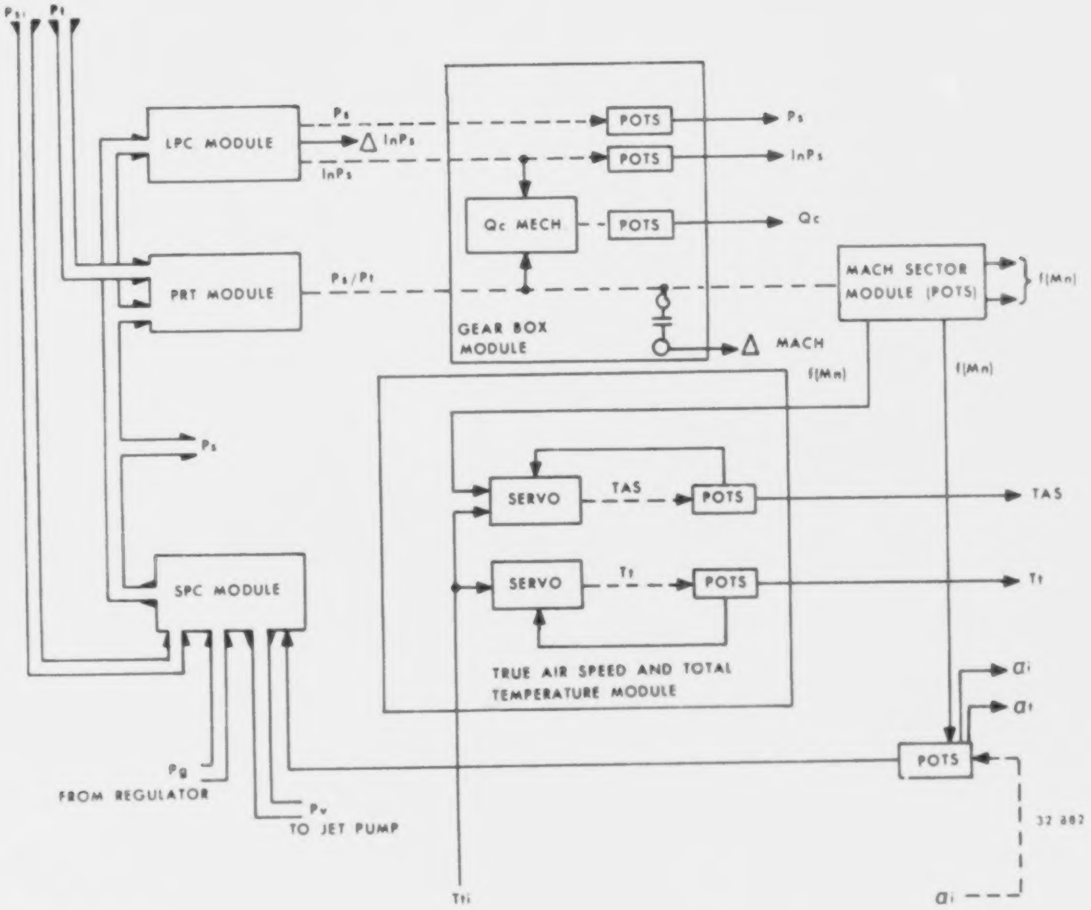
Ps
Pt
LPC MODULE
Ps
Δ lnPs
lnPs
POTS
Ps
POTS
lnPs
Qc MECH
POTS
Qc
PRT MODULE
Ps/Pt
MACH SECTOR MODULE (POTS)
f(Mn)
GEAR BOX MODULE
Δ MACH
f(Mn)
f(Mn)
Ps
SERVO
TAS
POTS
TAS
SERVO
Tt
POTS
Tt
TRUE AIR SPEED AND TOTAL TEMPERATURE MODULE
SPC MODULE
αi
αt
POTS
Pg
FROM REGULATOR
Pv
TO JET PUMP
32 882
Tti
αi

Figure 2-4. Computer block diagram (module breakdown).

2-3. CADC Module Inputs and Outputs

In this section, we will discuss the inputs and outputs to the different modules in the computer and computer servomechanisms and mechanizations.

A23. State the inputs and outputs of the log pressure controller module.

Log Pressure Controller (LPC) Module. The LPC is a force-balance device which receives Ps (pressure, static true) and generates, by means of shaft rotations, one output analogous to Ps and one output analogous to the natural logarithm of Ps. Refer to figure 2-4, computer block diagram (module breakdown), to better understand the following discussion.

The input to the log pressure controller (LPC) is a pneumatic true static pressure from the static pressure compensator (SPC) or an indicated static pressure when the SPC is inoperative. The outputs from the LPC are two shaft rotations and one synchro control transformer output. One shaft rotation is proportional to Ps and the second is proportional to natural logarithm static pressure (LnPs) (altitude). The synchro control transformer output is proportional to Δ LnPs (small change in natural logarithm static pressure) from any given engagement altitude.

Except for the amplifier which is not physically a part of the module, the LPC is a completely self-contained, feedback-type mechanism. The LPC output shaft gears drive the Ps and LnPs gears and shafts which are located in the gearbox module.

Exercises (A23):

1. State the inputs to the LPC.

2. State the outputs to the LPC.

A24. State the use of the static pressure compensator (SPC).

Static Pressure Compensator (SPC). The SPC is a force-balance device which corrects for static port sensing errors that generally occur in the transonic range because of shock waves. The compensator receives Psi (indicated static pressure), and a correction signal which is a function of Mach number and/or indicated angle of attack (AOA). It generates Ps (true static pressure) in the form of a pneumatic output.

Exercises (A24):

1. State what the static pressure compensator is used for.

2. What is used by the SPC to correct for the errors in the indicated static pressure?

A25. Specify the output and use of mechanical differentials.

Mechanical Differential. A mechanical differential is a device which produces an output shaft rotation which is the algebraic sum of the rotation of the two input shafts.

Mechanical differentials are generally used in air data equipment to facilitate solving problems by addition or subtraction of the logarithms of various functions. They also solve difficult multiplication or division problems by adding or subtracting logs by means of a simple differential gearing. Sometimes, however, a differential is used only as a corrective device on air data output shafts.

Exercises (A25):

1. What is the output of the mechanical differential?

2. What is the use of mechanical differentials in air data equipment?

A26. Cite the inputs and outputs to the Mach pressure ratio transducer (PRT) module.

Refer to figure 2-4, computer block diagram (module breakdown), to better understand the following discussion.

Pressure Ratio Transducer (PRT) Module. The PRT receives true static pressure from the SPC or indicated static pressure when the SPC is inoperative. The PRT also receives total pressure (Pt) from the pitot tube. The output from the PRT module is a gear rotation proportional to the ratio of Ps/Pt. The PRT is a self-contained feedback-type servomechanism. The PRT output gear drives the Ps/Pt shaft in the gearbox, which is the source of all pressure ratio information.

Exercises (A26):

1. Cite the inputs to the PRT module.

2. Cite the output to the PRT module.

A27. Name the inputs and outputs of the gearbox module.

Gearbox Module. The gearbox (see fig. 2-4) receives three mechanical inputs in the form of shaft rotations. The rotations are proportional to Ps, LnPs, and Ps/Pt respectively. The required outputs from the gearbox are as follows: three voltage ratios—one proportional to Ps, one proportional to LnPs, and one proportional to impact pressure (Qc); one gear rotation which is proportional to Ps/Pt; and a synchro control transformer output which is proportional to ΔMach from a given lock-in point. The precision potentiometers in the gearbox are driven by suitable gears and shafts. Within the gearbox, Qc is mechanized from functions of LnPs and Ps/Pt.

The shaft rotation which is proportional to Ps/Pt is used to provide an input to the Mach sector module. Since Mach number (Mn) is a function of Ps/Pt, Mach information is provided by a cam which is driven by the Ps/Pt shaft.

Exercises (A27):

1. What are the inputs of the gearbox module?

2. What are the outputs of the gearbox module?

A28. State what drives the main shaft of the Mach sector module and what the Mach sector's output information is.

Mach Sector Module. The main shaft of the Mach sector module (fig. 2-4) rotates linearly with Ps/Pt and is driven by the PRT via the gearbox. Attached to the Ps/Pt shaft in the sector unit are cams which have been cut to generate various Mach functions. The cam followers drive the wipers of precision potentiometer. Wiper positions and, therefore, voltage rations across the potentiometer cards are functions of Mn dependent upon Ps/Pt.

The Mach sector module is the source of all Mach or Mach function information.

Exercises (A28):

1. What drives the main shaft of the Mach sector module?

2. State the information output of the Mach sector module.

A29. Describe the signal that commands the TAS servomotor and state how the Tt probe appears to the Tt network.

True Airspeed (TAS) and Total Temperature (Tt) Module (fig. 2-4). Electrical signals analogous to function of Mn and Tt are applied to the circuit which commands the TAS servomotor. The function of Mn information used by the TAS circuit is sensed across a precision potentiometer in the Mach sector module. The Tti signal is provided by the total temperature probe. The servomotor produces a shaft rotation which is linear with TAS.

The outputs from the total temperature servo are in the form of voltage ratios and switch actions. The Tt probe appears to the Tt network as a variable resistance element. A change in Tti from a stabilized point creates an unbalance in the bridge and causes the servomotor to run. When the Tt followup potentiometer resistance again balances the bridge, the motor stops running. Shaft rotation is, therefore, proportional to Tt.

Exercises (A29):

1. Describe the signal that commands the TAS servomotor.

2. State how the Tt probe appears to the Tt network.

A30. Cite operating principles of static pressure and pressure ratio sensors.

Sensors. The operation of the static pressure sensor (SPS) and pressure ratio sensor (PRS), which are used in the LPC and PRT respectively, is described in the applicable module discussion. Some of the terminology used to describe sensor operation is not strictly realistic and requires some clarification before a complete understanding of sensors can be acheived.

In general, the sensors have pneumatic intelligence inputs and electrical outputs. The jackscrew shaft gear is often called the sensor output gear, but this term is misleading. The sensors have no servomotor contained in them, and it is, therefore, impossible for the sensor to drive the jackscrew shaft. The shaft, which is, in fact, driven by the module servomotor via a suitable gear train, provides a means of repositioning the sensor fulcrum to establish moment balance. The jackscrew gear is, therefore, an input to the sensor and provides a means of closing the sensor servoloop (it transmits feedback to the sensor).

Exercise (A30):

1. What are the inputs and outputs of static pressure and pressure ratio sensors?

A31. Describe the operation of elements of the log pressure controller (LPC).

Log Pressure Controller (LPC) Operation. The LPC is a computing element whose intelligence input is pneumatic Ps and whose servoloop is the source of all mechanical (shaft rotation) altitude (LnPs) and pressure (Ps) information. The LPC sensor is an extremely sensitive and accurate force-balance type instrument in which a bellows applies a force proportional to Ps to one "end" of a short stiff beam. An opposing force is applied to the opposite end of the beam by a torsion bar assembly, as shown in figure 2-5. The movable fulcrum supports the beam and is moved to a position of balance by the servodriven jackscrew. The movable armature of an E-core transformer is attached to the bellows end of th beam (see fig. 2-5).

The E-core transformer (fig. 2-6) consists of an E-shaped core with a winding on each leg of the core. The primary coil is wound around the center leg which is

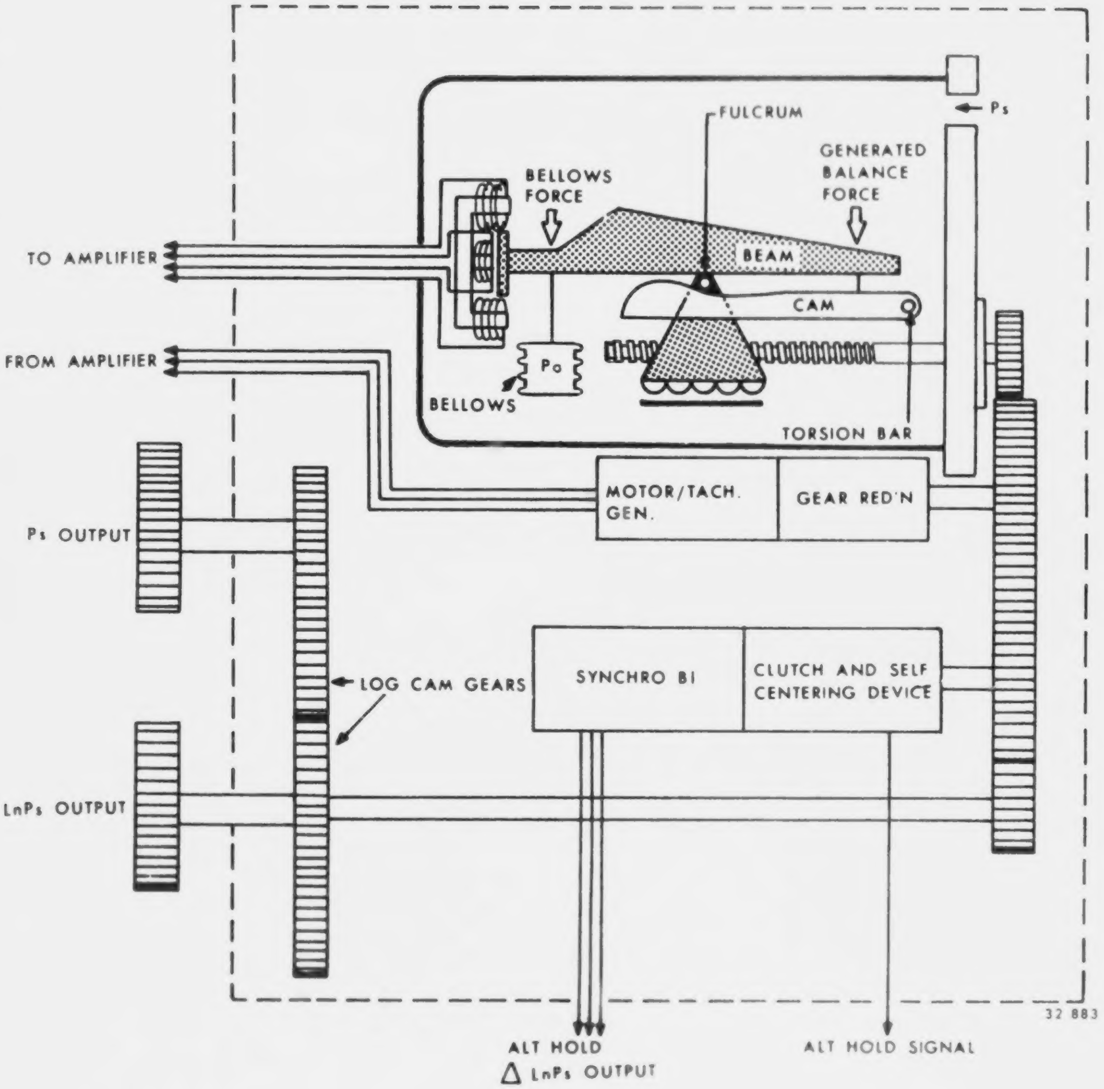
FULCRUM
Ps
GENERATED BALANCE FORCE
BELLOWS FORCE
TO AMPLIFIER
BEAM
CAM
FROM AMPLIFIER
Po
BELLOWS
TORSION BAR
MOTOR/TACH. GEN.
GEAR RED'N
Ps OUTPUT
LOG CAM GEARS
SYNCHRO BI
CLUTCH AND SELF CENTERING DEVICE
LnPs OUTPUT
32 883
ALT HOLD
Δ LnPs OUTPUT
ALT HOLD SIGNAL

Figure 2-5. Simplified schematic of log pressure controller.

shorter than the two outside legs. The continuous secondary is wound in opposition on the two outside legs. A 400-Hz AC is applied to the primary. The armature is mounted on a link on one end of the PRT beam and is suspended in the gap between the two outer legs of the core. With the armature in the exact center of the gap, the voltages induced in the two secondary windings are equal and of opposite sign at any instant of time. When the armature is moved from its center position by beam deflection, the reluctance of the magnetic path from the center leg of the core through the core of the outer leg is increased on one side and decreased on the other side. The secondary winding on the side with lowered reluctance will have induced in it a voltage greater than that on the other side. The voltage induced in coil A is 180° out of phase with the voltage induced in coil B because of the reversed direction of winding. Since the two windings are series-connected, the transformer output voltage will be equal to the algebraic sum of the voltage induced in the legs. The resultant output voltage is, therefore, representative of both magnitude and direction of beam displacement.

If the forces resulting from static pressure acting on the bellows and those resulting from the torsion bar windup are balanced because of the existing fulcrum position, the beam will remain at its undeflected position, and the output from the E-core will be effectively zero. If the static pressure changes, the beam will rotate about the fulcrum. The direction of beam rotation will be dependent upon the direction of change in static pressure. As the beam rotates, the E-core armature will be displaced, and an output voltage will appear across the transformer secondary. The direction of armature motion determines the transformer output phase as referenced to the input phase.

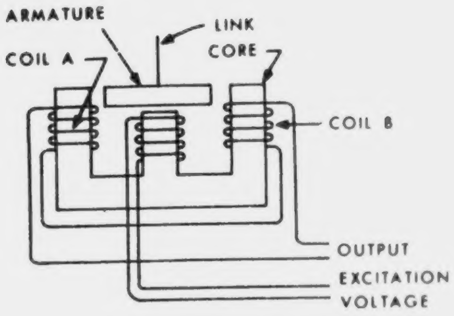

Figure 2-6. Schematic of E-core transformer.

The transformer output signal is passed through a phase-correcting network and a coupling transformer to the LPC servoamplifier. With an input signal above null value, the amplifier will produce an output which will cause the LPC servomotor to run. The phase of the signal to the motor is compared to a motor reference phase (115 volts, 400 Hz) to determine the direction of motor and gear-train rotation and sensor fulcrum movement. The sensor jackscrew will then be turned in the correct direction to reposition the fulcrum so that the beam is once again balanced and the E-core transformer output is zero.

Because of the moveable-fulcrum configuration of the static pressure sensor, the fulcrum positions and jackscrew rotations are very nearly linear with LnPs. It is, therefore, relatively easy to exactly linearize (within tolerances) the jackscrew rotations to be proportional to LnPs by means of a cam which varies the torsion bar force as a function of fulcrum position. During the time the servomotor is running, two shaft rotation outputs are made available to other computer components which require Ps and/or LnPs information. You can see in figure 2-5 that fulcrum position is proportional to rotational displacement of the LnPs shaft. The second shaft (Ps) must, because of the log cam gears, rotate in a manner which is linear with Ps. In actual operation, the LnPs shaft drives the Ps shaft using the log cam gears; hence the rotation of the second shaft is the antilog of the rotation of the driving shaft.

Exercises (A31):

1. Describe the input and output to the LPC.

2. Describe how the windings are wound on the outside legs of the E-core.

3. Describe the phase relationship of the induced voltages of coils A and B of the E-core. Why?

4. Describe what determines the direction of the fulcrum beam rotation in the LPC.

5. What does the movable fulcrum configuration of the static pressure sensor cause?

A32. State operating characteristics of the altitude hold portion of the LPC.

Altitude Hold Δ Altitude. Information regarding change in altitude (ΔLnPs) from a pilot-selected, lock-in point is also provided by the LPC. When the ALTITUDE HOLD mode is selected by the pilot, the ΔLnPs clutch engages and the rotor of the synchro control transformer B1 of figure 2-5 is mechanically connected to the LnPs shaft. The synchro had previously been held at electrical zero by a mechanical centering device which is a part of the clutch/synchro assembly. With the ALTITUDE HOLD mode selected, any change in aircraft altitude will cause the rotor of synchro B1 to rotate and generate a voltage output which has a magnitude proportional to the amount of altitude change. The phase of the synchro output will be determined by the direction of LnPs change (+ or −). The synchro output is transmitted to the automatic flight control system (AFCS) which will then take the necessary corrective action to reestablish the altitude the aircraft was holding at the time of lock-in.

Exercises (A32):

1. State what happens in the LPC when altitude hold is selected.

2. State the phase of the synchro B1 output.

A33. Using a block diagram as a reference, describe operating principles of the pressure ratio transducer module.

Pressure Ratio Transducer (PRT) Operation. The PRT is a computing element which accepts pneumatic Ps and Pt input signals and, by means of a servoloop, provides a shaft rotation output proportional to the ratio Ps/Pt. The actual mechanization of Ps/Pt is accomplished in the pressure ratio sensor (PRS), and the sensor "output" is transmitted via a suitable gear train to the PRT output shaft (see fig. 2-7).

Within the sensor, a force proportional to the Ps pressure is applied to one end of the short stiff balance-beam by means of an evacuated bellows. A force proportional to Qc pressure is applied near the other end of the beam by means of a differential bellows. The movable fulcrum is positioned by a jackscrew which is rotated by a servomotor through the gear train. The movable armature of the E-core transformer is attached to one end of the beam. If Ps and/or Pt change in such a manner as to change the value of Ps/Pt, the beam becomes unbalanced, the E-core armature moves, and an output signal appears across the transformer secondary. The transformer output provides an input to the servo-amplifier contained in the module and the servomotor begins to run. The phase of the transformer output, as referenced to the transformer input, determines the direction of motor rotation and thus the direction of jackscrew rotation and fulcrum movement. The jackscrew will turn until the fulcrum is positioned so that the beam is once again balanced, and the E-core transformer output is zero (below threshold of amplifier).

Since the sensor fulcrum must be moved when the ratio Ps/Pt changes, the turning of the sensor jackscrew, the module gear train, and the module output shaft is a mechanical analog of Ps/Pt.

The servomotor which is used to correct fulcrum position is phase-sensitive so that the proper gear train rotation direction is realized when an error signal is developed. The motor phase-sensitivity is achieved by using an AC motor with a reference winding and by connecting each end of the motor control winding to one of the amplifier output transistors. The transistor collector voltage source is connected to the control winding center tap. The result of the aforementioned operation is that when an error signal of one phase (caused by E-core armature displacement in one direction) is received by the amplifier, the amplifier output to the motor will be 90° "ahead" of the motor-reference phase and will cause the motor to run in one direction. When the

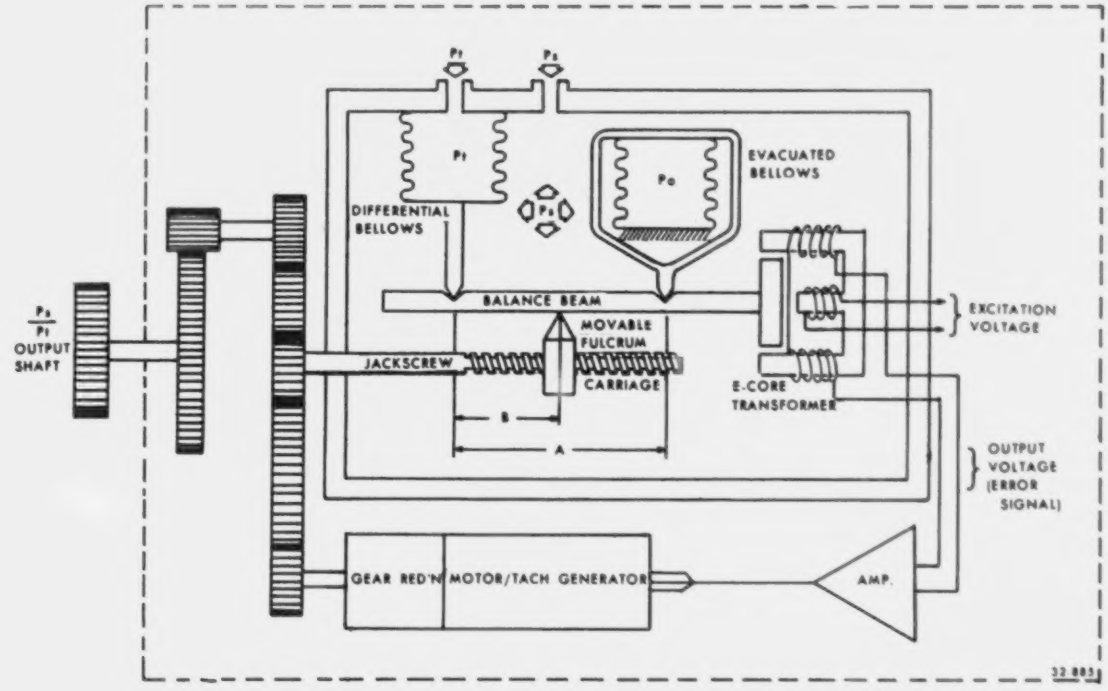

Figure 2-7. Simplified schematic of pressure ratio transducer.

E-core transformer armature is moved (in the opposite direction) to set up a voltage of opposite phase, the amplifier output phase will be 90° "behind" the motor-reference phase, and the motor will run in the opposite direction.

When the motor has driven the fulcrum to the new position which will rebalance the beam and, therefore, center the armature, the error signal is reduced to zero (below amplifier threshold voltage) and the motor stops running. To prevent servoloop instability and overshooting, a trachometer winding is included in a tachometer generator in the servomotor assembly. The output of the generator provides negative feedback to the amplifier. When a large error signal exists, the motor and generator will turn quite rapidly and develop a large value of negative feedback. To preclude system response time being extended beyond desirable limits by excessive values of feedback voltage, resistors have been incorporated in the circuit. With the feedback voltage being applied through this circuit in opposition to the E-core output, correct damping of the servocircuit is attained.

Exercises (A33):

1. Where is the actual mechanization of Ps/Pt accomplished?

2. Describe the force applied to the balanced beam by the differential bellows.

3. What does the phase of the transformer output in reference to its input determine?

4. Why is the correct fulcrum position phase-sensitive in the PRT?

5. Describe how the motor in the PRT is made to operate in one direction and then describe how it will operate in the opposite direction.

6. How is instability and overshooting prevented in the servoloop?

A34. Using a block diagram as a reference, state operating principles of the static pressure compensator.

Static Pressure Compensator (SPC) Operation. The SPC (fig. 2-8) receives Psi (pneumatic) and programmed electrical functions of Mach number and angle of attach inputs and is the source of pneumatic Ps for all using CADC and aircraft systems.

The SPC is also a force balance instrument, although its servosystem functions in essentially the reverse manner of the PRT servosystem. The SPC uses a beam and a movable fulcrum which is driven by a jackscrew. A force proportional to Psi minus case pressure (Ps when the SPC is functioning properly) is applied to one "end" of the beam by diaphragm. A force proportional to case pressure is applied to the opposite "end" by an evacuated bellows. When the movements (resulting from the applied forces) about the fulcrum are equal, the beam will balance.

The poppets of the two pneumatic control valves are actuated by beam movement by means of a wire flexure. When opened, one control valve permits the flow of air at a pressure greater (Pg) than case pressure to enter the case. When the second control valve is opened, case pressure is bled off to a vacuum source (Pv) which is developed in the low-pressure chamber of a jet pump.

When the beam is in its balanced, undeflected position, both control valves are closed, and the case pressure (Ps) holds at a constant value. When a programmed correction signal is applied to the SPC servoamplifier, the fulcrum carriage servomotor runs and drives the jackscrew to move the fulcrum to a new position. When the voltage picked up by the wiper of the SPC followup potentiometer balances the SPC command circuit (not shown), the servomotor stops running. The beam, which had been in balance with the fulcrum in its first position, now deflects and causes one of the control valves to open. The direction of beam deflection determines whether the high- or low-pressure (with respect to case pressure) valve will open.

When the proper control valve opens, as determined by beam deflection, a pressure either higher or lower than case pressure is introduced into the case. The beam will then achieve balance about the new fulcrum position by the action of the diaphragm and evacuated bellows.

Exercises (A34):

1. State the two forces applied to the balanced beam in the SPC.

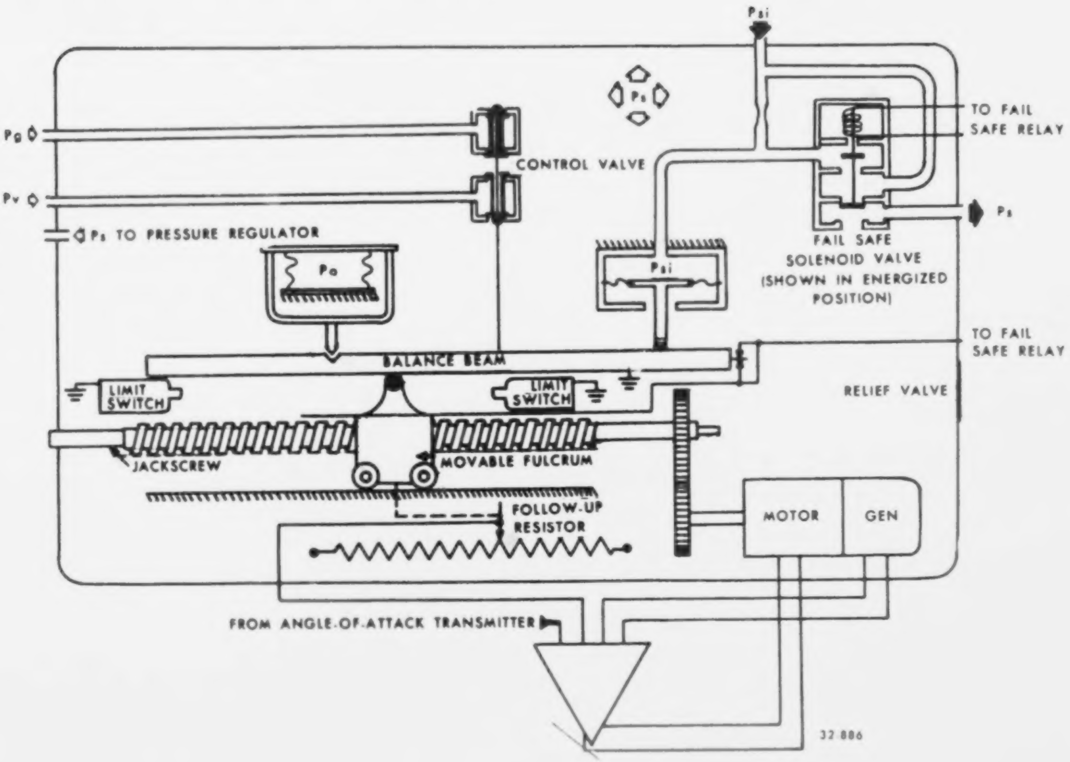
Psi
Ps
Pg
Pv
CONTROL VALVE
Ps TO PRESSURE REGULATOR
Po
Psi
TO FAIL SAFE RELAY
Ps
FAIL SAFE SOLENOID VALVE (SHOWN IN ENERGIZED POSITION)
TO FAIL SAFE RELAY
RELIEF VALVE
BALANCE BEAM
LIMIT SWITCH
LIMIT SWITCH
JACKSCREW
MOVABLE FULCRUM
FOLLOW-UP RESISTOR
MOTOR
GEN
FROM ANGLE-OF-ATTACK TRANSMITTER
32 886

Figure 2-8. Simplified schematic of static pressure compensator.

2. How is the case pressure in the SPC increased or decreased?

3. What is the condition of the control valves when the balance beam is balanced?

4. What does the direction of balance beam deflection determine?

A35. With a SPC fail-safe diagram, describe the fail-safe circuit operation.

Fail-Safe. A fail-safe solenoid valve (fig. 2-8) is included in the SPC to protect the system and aircraft in the event of an SPC failure. With the solenoid valve in the failed position, Psi is routed directly into the Ps lines. The introduction of the uncorrected Psi, will, of course, induce errors in the Ps-dependents systems, but the systems will still remain operable.

The fail-safe relay (which operates the solenoid valve) is also tripped if a malfunction such as a diaphragm rupture causes the beam to deflect an extreme amount and contact the switch at the end of the beam. Limit switches, which are actuated by excessive fulcrum carriage travel, also perform the same function.

Failure of the SPC in the presence of a transient disturbance is prevented by installation of a time-delay relay (solid state) in the fail-safe circuit. The time-delay relay requires about 0.3 second to deenergize the solenoid valve. A failure in the aircraft electrical power supply will also dump the solenoid valve and vent Psi directly into the Ps system. Figure 2-9 is a simplified schematic of a fail-safe circuitry. When aircraft power is applied, the computer power supply system delivers 70 VDC to terminal 2 of relay K2. The application of this voltage applies a bias voltage on the base of Q2 transistor, turning it on (gate open). By having Q2 open, conditions have been established for the operation of Q1. The 28-VDC aircraft power is applied to terminal 5 of relay K2. With Q2 gating, a base-emitter bias on Q1 will be established across R6 as a function of the resistance of R5 and Q2 to ground. Under these conditions, Q1 will turn on (gate open) and allow 28 VDC to flow from the emitter to the collector and out of K2 relay through terminal 4 to terminal 9 of K3 relay. If the cockpit reset switch is momentarily moved to the "RESET" position, 28 VDC will be applied to the coil of K3 through the normally closed contacts and through terminal 10 of K3.

Once K3 has been energized, it is held in the energized position by the 28 VDC power through contacts 8 and 9 through the normally closed terminals of the reset switch, and through terminal 10 to the coil. When K3 is energized, contacts 6 and 7 close and supply 28 VDC to the fail-safe solenoid valve L9 in the SPC. With L9 energized, Ps is routed to the SPC output.

When either of the SPC light switches or the beam switch is actuated for longer than 0.2 second, relays K2 and K3 and the fail-safe solenoid valve are denergized, Psi is routed to the SPC outlet, and contacts 2 and 3 and of K3 close and cause the cockpit fail-safe lamp to light.

The time-delay characteristics of relay K2 are provided as follows: If any one of the fail-safe switches is actuated, terminal 2 of K2 relay is at ground potential and the 70 VDC is dropped across R1. CR1 will prevent the feedback of voltage on the transistor base from flowing to ground through the closed switch. The transistor base voltage will be bled off by the action of the R-C circuit (R2, R3, and C1) to ground. The R-C constant is designed so that after an interval of 0.3 second the level of voltage on the base of Q2 will have dropped to the point where Q2 will turn off (gate closed). When Q2 is turned off, the level of voltage rises on the base of Q1, changing the base-emitter bias and turning off Q1. With Q1 turned off, the 28 VDC is no longer available to the coil of the K3 relay, and it drops out. Wilth K3 relay open, the fail-safe solenoid L9 is deenergized.

The manually operated switch, which is located in the cockpit, permits reset of the fail-safe solenoid valve. If the malfunction which caused the relay to trip has cleared, the SPC will again apply correction to Psi. However, if the fail circuit is still energized, the reset switch will have no effect. If the pilot wishes to eliminate the SPC from the system, he may do so by moving

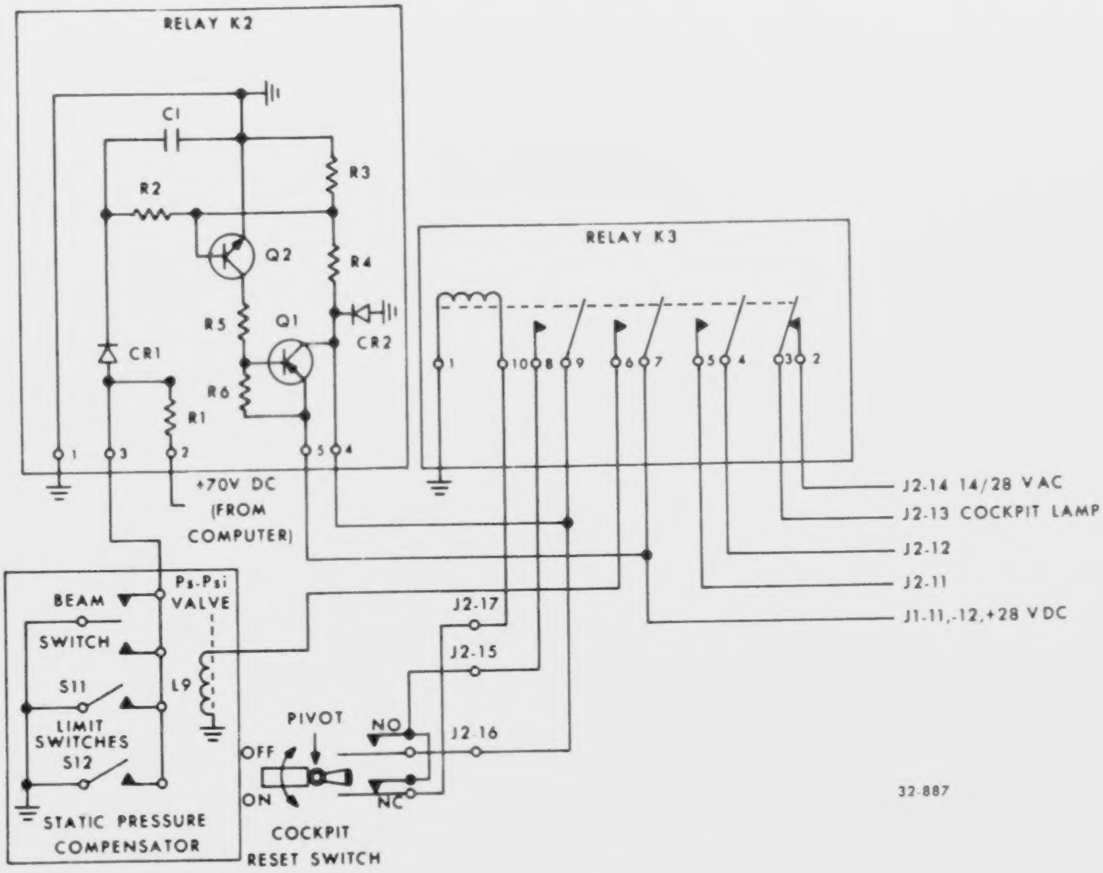
RELAY K2
C1
R2
R3
Q2
R4
R5
Q1
CR2
CR1
R6
R1
1
3
2
5
4
+70V DC (FROM COMPUTER)
RELAY K3
1
10
8
9
6
7
5
4
3
2
J2-14 14/28 VAC
J2-13 COCKPIT LAMP
J2-12
J2-11
J1-11,-12,+28 VDC
BEAM SWITCH
Ps-Psi VALVE
S11
L9
LIMIT SWITCHES
S12
STATIC PRESSURE COMPENSATOR
J2-17
J2-15
J2-16
PIVOT
NO
NC
OFF
ON
COCKPIT RESET SWITCH
32-887

Figure 2-9. Simplified schematic of fail-safe circuitry.

the reset switch to its OFF position. In this position, the fail circuit is energized, and Psi is supplied to the Ps system.

A pressure relief valve, which is installed in the end of the SPC case, will open if the pressure differential between case and ambient exceeds approximately 5 psig. Once the valve has opened and reduced the internal case pressure to the proper level, it will reseat automatically.

Exercises (A35):

1. Describe what happens when the fail-safe solenoid is in the failed position.

2. What is incorporated in the SPC to protect it in case a diaphragm ruptures?

3. What is incorporated in the SPC to prevent failure in the event of transient disturbances?

4. What happens when the cockpit reset switch is momentarily moved to the reset position?

5. Describe the purpose of CR1 in figure 2-9.

6. Describe what happens when the reset switch is turned to the OFF position.

A36. State operating principles of the total temperature and true airspeed servo.

Total Temperature and True Airspeed Servo. The temperature sensed by the total temperature probe is Tti, which requires a correction proportional to airplane Mach number. This correction is the square root of Tti. The square root of Tti is developed by making the total temperature probe part of a bridge circuit. The output of the bridge circuit, which is an electrical signal proportional to the square root of Tti, is applied across a resistor. A cam, which is located in the Mach sector box and which is driven by the Ps/Pt shaft, positions the wiper of the resistor. The position of the resistor wiper varies. Thus, the signal at the wiper of the resistor is proportional to TAS.

The TAS signal picked up by the wiper of the resistor is fed to the TAS servoamplifier and causes the servomotor to run. As the motor runs and turns the TAS shaft, a followup potentiometer wiper is moved, balancing the bridge circuit and mulling the signal to the amplifier. Oscillation damping is provided by the feedback generator wich turns with the servomotor.

The same square root of the Tti signal that is applied to the resistor of the TAS servosystem is applied to the servoamplifier of the total temperature system. As the Tt servomotor runs and turns the Tt shaft, the wiper of another resistor is rotated. The voltage picked up by this followup wiper is developed in a bridge that effectively removes the quantity of the square root of Tti and causes the servomotor rotation to be linear with Tt. As in the TAS servosystem, oscillation is prevented by feeding back a generator output.

Another resistor was included to prevent the TAS and Ti servosystems from running away when the temperature probe is removed from the circuit. When the probe is installed, this resistor is shorted by an internal connection in the probe.

Exercises (A36):

1. State the output when Tti is corrected for airplane Mach number.

2. State how oscillation damping is provided in the TAS servo.

3. State the relationship of servomotor motor rotations and Tt.

4. State how the servosystems are prevented from running away when the temperature probe is removed.

A37. Describe operating principles of the impact pressure and Mach hold mechanisms.

Impact Pressure (Qc) Mechanization. Impact pressure is mechanized in the gearbox from rotational information supplied by the Ps/Pt shaft and the InPs shaft.

A cam, which is mounted on the Ps/Pt shaft, has been cut to generate and transmit Ln(Qc/Ps) to a follower and sector gear.

A sector gear applies to one side of a mechanical differential a rotational input analogous to the quantity

Ln(Qc/Ps). The second input to the differential is a rotation which is analogous to LnPs (generated by the LPC). When these two rotational inputs are algebraically summed, the differential output is a rotation proportional to LnQc. Attached to the LnQc output gearing is a suitable spring load to remove the inherent lash that could occur in this type of mechanization. The Qc potentiometers are attached to the LnQc shaft.

Mach Hold Mechanization. A cam on the PsPt shaft in the gearbox is cut to generate Mn as a function of Ps/Pt.

A switch on the pilot's instrument panel permits selection of the MACH HOLD mode. When this mode is selected, an electrical clutch is energized and the synchro mechanical self-centering device is overridden. Once the clutch has been engaged at a certain flight condition, any change in Mach number from the lock-in value will cause the shaft of the synchro control transformer to rotate from its null position, and a synchro output voltage will appear.

The phase of the synchro output (as referenced to input) and the magnitude of the output inform the autopilot (AFSC) system of the direction and magnitude of the Mach deviation from the lock-in value. The autopilot will then take corrective action to reestablish the lock-in flight conditions. In doing so, the autopilot will cause the aircraft speed, and therefore the Ps/Pt, to return to lock-in value. During the corrective process, the synchro output drops to zero.

Exercises (A37):

1. When the two inputs to the mechanical differential are algebraically summed, what is the output?

2. State how inherent lash is removed from the output gearing of the Qc mechanisms.

3. State what happens when the MACH HOLD mode is slected on the instrument panel.

A38. Describe how true angle of attack is obtained.

True Angle of Attack (at). Since indicated angle of attack (ai) deviates from true angle of attack at certain flight Mach conditions, ai is corrected for the function of Mn by two potentiometers in the Mach sector module. The potentiometer wipers are positioned by cams which are driven by the Ps/Pt shaft.

The variation of ai is generally linear and merely rerequires slope and intercept corrections. Intercept correction is provided as a function of Mn by a resistor, and slope correction is provided by another resistor in the Mach sector module.

The outputs from the wipers of the two resistors, in conjunction with the other bridge components, impress a voltage across the potentiometer in the angle-of-attack transmitter. This voltage is picked off by the latter's wiper and is proportional to at. For convenience of use by concerned systems, the ratio of voltage to at is 1 volt/degree.

Exercises (A38):

1. Describe how the variation of ai is corrected.

2. Describe the relationship ai generally has with at.

A39. Describe the computer servoamplifiers and state the computer power requirements and operating principles of the gauge pressure regulator assembly.

Computer Servoamplifiers. Four identical plug-in servoamplifiers are used in the computer. A fifth servoamplifier, which differs both in construction and circuitry, has been discussed in an earlier part of this section dealing with the PRT. Figure 2-10 is the simplified schematic of the servoamplifiers.

Each amplifier uses six N-P-N transistors in a conventional 3-stage, push-pull, transformer coupled circuit. An unusual feature of the amplifier is the feedback transformer T6 which is connected from emitter to emitter of the final stage. A variable resistor, R40, connected across the feedback transformer, controls the amount of negative feedback. The output of the feedback transformer is connected in series with the winding of the input transformer T9. The leads from terminals 9 and 10 of the amplifier connector to go to the emitters of the first stage. This circuit carries a rate control signal from the feedback generator in the concerned servosystem.

Power Requirements. Primary operating power required for computer operation includes: 115V, 3-phase, 400-Hz alternating current for servomotors and inputs to secondary power supplies; 28 VDC for clutches, relays, TAS indicator servoamplifiers, and fail-safe circuitry; 26V 400 Hz for TAS synchro and TAS indicator servomotor reference winding excitation.

The precision variable resistors in the CADC are excited by various voltages which are not classified as power supply inputs.

Gauge pressure regulator assembly. The gauge pressure regulator provides a source of air for the computer that is at a pressure greater than Ps. (This pressure is called Pg.)

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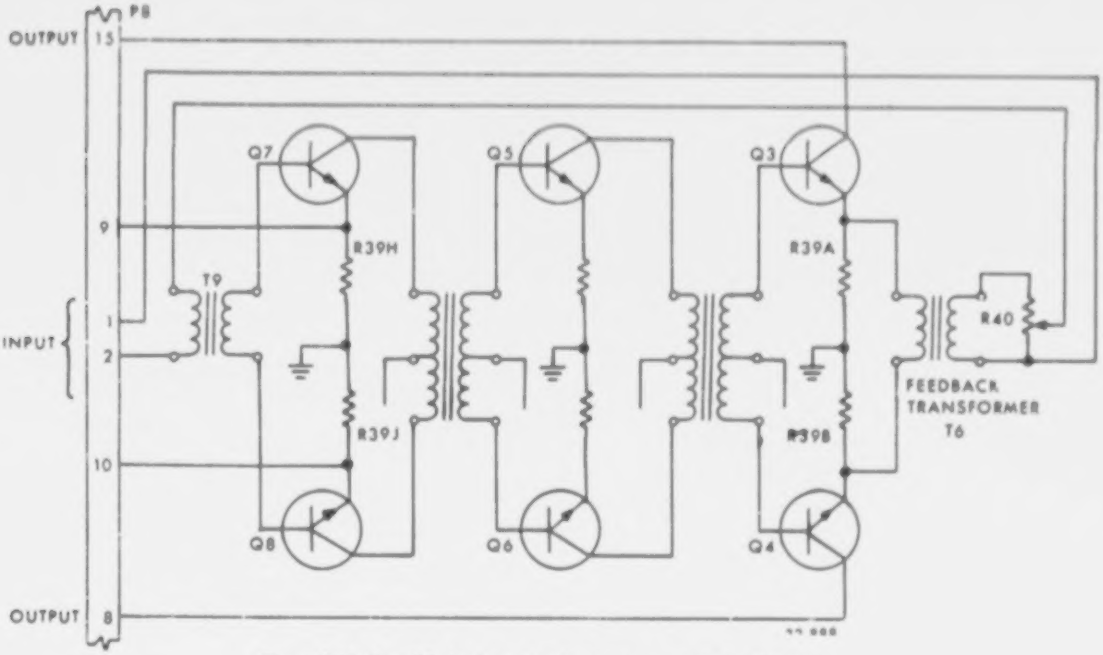

Figure 2-10. Simplified schematic of computer amplifier assembly.

Engine bleed air is fed to the input port (Pr) of the regulator assembly. The regulator output (Pg) goes to the high-pressure control valve in the SPC. A line from the SPC case provides Ps to the regulator to serve as a reference pressure. The purpose of the reference is to provide the proper ΔP between SPC case pressure (Ps) and Pg at all altitudes.

Ps acts upon an evacuated bellows and applies pressure to one side of a control diaphragm. The adjustable load-spring provides compensation for bellows spring rate and preloads the regulator. Pg acts upon the opposite side of the control diaphragm to which is attached a balanced poppet valve. The poppet valve is designed so that its two surfaces are of equal area. Forces resulting from the application of Pr to these surfaces are therefore equal and opposite and do not affect valve operation.

An increase in Ps causes the diaphragm to move away from the bellows and opens the poppet valve. As the poppet valve opens, Ps increases and forces the diaphragm in the opposite direction, thereby, closing the poppet. By this action, Pg follows Ps by a fixed amount throughout the aircraft flight envelope.

Exercises (A39):

1. Describe the purpose of R40 in figure 2-10.

2. State the power required to operate the servomotors and secondary power supplies in the computer.

3. State the purpose of the gauge pressure regulator assembly.

4. What provides a compensation for bellows spring rate in the gauge pressure regulator assembly?

5. State the relationship of Pg and Ps throughout the flight envelope.

A40. With a CADC wiring diagram, describe electrical missile output functions.

Missile Outputs. Refer to foldout 1 for the following discussion. (The output systems are not shown on this diagram).

The first signal output we will discuss is the missile range interlock signal. This signal is provided by the precision variable resistor R21B (top center of the diagram). It provides a Ps output that is supplied by a shaft driven by the LPC.

The signal for missile lead angle "A" (alt) is supplied by a precision variable resistor R21A (top center of FO 1) that supplies a Ps output and is driven by the LPC.

There is a signal supplied to missile range interlock "B" (alt) by precision variable resistor R20A (top center *of FO 1) that supplies an LnPs output and is driven by* the LPC.

An LnPs output signal is supplied to the missile range interlock altitude computer by the percision variable resistor R20C (top center of FO 1) and is driven by the LPC.

A signal is supplied to the missile range interlock "A" (TAS) from precision variable resistor R60B (lower right corner of FO 1) and is driven by the TAS shaft.

There is an output to missile lead angle "B" (at) from a precision variable resistor in the angle-of-attack transmitter (lower left corner of FO 1).

Exercises (A40):

Use foldout 1 when answering the following exercises:

1. From where are the Ps signals for the outputs to the missile functions driven?

2. What actuating source applies a signal to the missile lead angle?

A41. With a CADC wiring diagram, state the use of outputs from the TAS section.

TAS Outputs. The outputs from the TAS sections are used as follows:

a. A TAS signal is applied to the navigation computer "A" from precision variable resistor R60D (lower right corner of FO 1). The signal is actuated through the TAS shaft.

b. A TAS signal is also applied to the navigation computer "B" from precision variable resistor R60E (lower right corner of FO 1). The signal is actuated through the TAS shaft.

c. A TAS signal is sent from precision variable resistor R60F (lower right corner of FO 1). The variable resistor sends a TAS signal to the TAS shaft, but is used as a spare.

d. A TAS signal is sent from precision variable resistor R60C (lower right corner of FO 1). This variable resistor sends a TAS signal to the TAS shaft that drives the stick force to stabilator.

e. A TAS signal is applied to switch S14 (lower right corner of FO 1). This switch causes the flaps to raise at 190 knots TAS.

f. A TAS signal is applied to switch S15 (lowr right corner of FO 1). The switch causes the rudder feel system to close at 190 knots TAS.

Exercises (A41):

Use foldout 1 when answering the following exercises:

1. How are the TAS signals actuated to the navigation computer?

2. For what is the TAS signal from precision variable resistor R60F used?

3. For what is the TAS signal from precision variable resistor R60C used?

4. The TAS signal to the TAS switches causes the flaps to raise at what speed?

A42. Using CADC wiring diagram, describe the use of the CADC outputs that are driven by the Qc and Tt outputs.

Qc and Tt Outputs. The Qc and Tt outputs are as follows:

a. There is a Qc signal output to the pitch rate to stabilator from precision variable resistor R19B (upper right corner of FO 1). The signal is actuated through the Qc shaft.

b. A Qc signal output is applied to the impact pressure lateral acceleration from precision variable resistor R19A (upper right corner of FO 1). The signal is actuated through the Qc shaft.

c. A Qc signal output is applied to the pitch altitude to stabilator from precision variable presistor R19C (upper right corner of FO 1). The signal is actuated through the Qc shaft.

d. A Tt signal output is applied to the ramp position output "A" from precision variable resistor R53B (lower right corner of FO 1). The signal is actuated through the Tt shaft.

e. A Tt signal output is applied to the ramp position output "B" from precision variable resistor R53C (lower right corner of FO 1). The signal is actuated through the Tt shaft.

f. A Tt signal output is applied through switch S13 (lower right corner of FO 1). The switch is operated by the Tt shaft-operated cam.

Exercises (A42):

Use foldout 1 when answering the following exercises:

1. Describe the CADC output that operates the pitch rate to stabilator.

2. Describe the CADC output that operates the impact pressure lateral acceleration.

3. Describe the CADC output that operates the pitch attitude to stabilator.

4. Describe the CADC Tt output to the ramp position output "B."

A43. Describe the use of the CADC outputs that are driven by the LnPs shaft and shaft cam.

LnPs Outputs. The LnPs outputs are as follows:

a. There is an LnPs signal output to the altitude computer and then to the navigation computer from precision variable resistor R20E (top center of FO 1). The signal is actuated through the PnPs shaft.

b. An LnPs signal sent from precision variable resistor R20D (top center of FO 1). It sends an LnPs signal to the LnPs shaft, but is used as a spare.

c. An LnPs signal applied through pressure altitude switches S6 and S8 (upper right corner of FO 1). Switch S6 closes at 17K feet, and switch S8 closes at 42K feet.

d. There is an LnPs signal applied through pressure altitude switch S7 (upper right corner of FO 1). Switch S7 closes at 32K feet.

Exercises (A43):

Use foldout 1 when answering the following exercises:

1. Describe the CADC output that operates the altitude and the navigation computer.

2. At what altitude does the switch S8 in the CADC close?

3. At what altitude does switch S7 in the CADC close?

A44. Using the appropriate diagram, describe the use of the CADC outputs that are driven by other miscellaneous outputs.

Miscellaneous Outputs. CADC outputs that are driven by other miscellaneous outputs are as follows:

a. There is Δ LnPs output to altitude hold from synchro B1 (upper left corner of FO 1). The signal is actuated through MG1 of the LPC when the clutch is energized.

b. There is a function of Mn output to the rate to rudder from precision variable resistor R26 (center of FO 1). The signal is actuated through a cam on the Ps/Pt shaft and is driven by the PRT.

c. There is a function of Mn output that is modified by ΔLnPs to control the stabilator from precision variable resistor R28 (center of FO 1). The signal is actuated through a cam on the Ps/Pt shaft and is driven by the PRT.

d. There is a ΔMn output to the ΔMach incremental from synchro B3 (upper right corner of Fo 1). The signal is actuated through a Ps/Pt shaft and is driven by the PRT when the clutch is energized.

e. There is a Mach signal through Mach switch S9 (upper right corner of FO 1). The switch is actuated by a Ps/Pt shaft-operated cam. The Mach switch closes at 0.98 Mach.

f. There is a Mach signal through Mach switch S10 (upper right corner of FO 1). The switch is actuated by a Ps/Pt shaft-operated cam. The Mach switch closes at 0.4 Mach and opens at 0.98 Mach.

Exercises (A44):

Use foldout 1 when answering the following exercises:

1. Describe the CADC output that operates the yaw rate to rudder.

2. Describe the CADC output that operates the Δ Mach incremental.

3. At what Mach does switch S9 in the CADC close?

4. At what Mach does switch S10 in the CADC close and open?

2-4. CADC Maintenance

Maintenance on the central air data computer system consists of performing inspections, operational checks, troubleshooting, and bench checks. Of course, you must use the related test equipment. These maintenance tasks are covered in the following paragraphs.

A45. List CADC inspection and operational check requirements.

Inspections and Operational Checks. Your inspection of the central air data computer system consists of checking each component for physical damage, proper installation, and safetying. Because the air data comper is shock mounted, check the shock mounts for deterioration. The central air data computer system has built-in self-test circuits to operational check the system. When the BIT switch is depressed, relays are energized which select fixed tap points on precision variable resistor assemblies within the computer. The fixed tap points simulate computer electrical outputs which are representatives of 0° at, 40,000 feet ± 100 altitude, and 800 ± 30 knots TAS.

The BIT circuitry does not functionally check out computer operation; the only qualitative test performed is a continuity check of the precision variable resistors in the circuits.

Exercises (A45):

1. List inspection requirements of the CADC.

2. List the results of an operational check of the CADC.

A46. State troubleshooting procedures for the CADC system.

Troubleshooting. When you troubleshoot the central air data computer system, use the TTU-205 test set. We have already covered this tester except for the temperature simulator function. The range of this function is 30.0 to 129.9 ohms, which is equal to approximately −99° to +430° Centigrade. You use the simulator to simulate temperature settings by using different resistance values which may be selected in 0.1-ohm increments. The TEMP OUTPUT receptacle provides a method of connecting the simulated temperature to the unit under test.

Use the TTU-205 to supply all of the required pneumatic pressure inputs to the air data computer. You may also use it to supply a known resistance to simulate the temperature probe input to the computer.

Troubleshooting a defective system is usually the most time-consuming part of any job. Before starting any troubleshooting task, know the complete system on which you are working. Also, think about what you are going to do before you start—to insure that you don't make any unnecessary time-consuming steps. The following paragraphs outline procedures that will help in your troubleshooting procedures. Keep in mind that technical order procedures for specific equipment should be followed.

When troubleshooting, insure that all the air data computer systems (ADC) circuit breakers are set. Check all the ADC external sensors to insure they are serviceable. Insure that the ADC test plugs are properly installed. Insure all pneumatic and electrical connectors are properly mated.

Then, check for a pitot or static leak in the system. If there is a leak, it must be repaired before you perform any other checks. When the pitot-static system is tight and there are no leaks, continue troubleshooting. The system can be checked for proper operation and to see if the indicators are functioning and indicating properly. If there are no leaks and all components operate satisfactorily, there must be trouble in the wiring. With a multimeter and a wiring diagram, you should be able to locate your problem by making voltage and continuity checks.

You are already aware that troubleshooting is performed so as to isolate line replaceable units and/or aircraft wiring, cabling, or plumbing. Aircraft that use an air data computer have malfunction system indexes, schematics, and troubleshooting procedures listed in the aircraft ADC flight-line maintenance technical order. The system symptoms are usually listed in alphabetical order, and they direct the user to a specific troubleshooting procedure. Troubleshooting using these charts is usually based on the idea that the observed symptom is caused by one malfunction. The flight-line ADC technical order with usually direct you to the appropriate technical order in the event the symptom is being caused by more than one malfunction.

To troubleshoot a particular malfunction, locate the component which malfunctioned in the indication of trouble column of the troubleshooting table. Directly adjacent to the selected symptom, the troubleshooting procedure column contains a reference to the troubleshooting procedure, location, or maintenance action to be performed.

When the troubleshooting procedure column refers to another manual, locate the symptom in the symptom index in that manual for a reference to the troubleshooting procedure.

When the troubleshooting procedure column refers to a particular paragraph, refer to that paragraph and follow the troubleshooting procedure. The troubleshooting procedure contains a series of steps with a NO-YES column which directs you to the malfunction isolation. When the term "is continuity present?" is used, the following should be checked:

- Check for loose electrical connectors and bent or broken pins.
- Check for continuity between specified pins.
- Check for proper shielding.
- Check for shorts to ground and between wires.

When the troubleshooting procedure column refers to a particular figure, refer to that figure, locate the component on the schematic, and logically troubleshoot the relating circuitry to isolate the malfunction.

When the troubleshooting procedure column contains a maintenance action to be performed, no isolation is required, and the maintenance action will correct the malfunction.

After the system troubleshooting and repair action is completed, the system requires an operational check. The operational check requires the use of the TTU-205 discussed in the previous objective. In the event the ADC was removed and replaced during your troubleshooting (or during maintenance action) it needs to be taken to the shop for bench check and repair, which we will discuss next.

Exercises (A46):

1. To begin troubleshooting the ADC system, insure the ____________ ____________ are set, all the ____________ sensors are serviceable, the ADC ____________ plugs are properly installed, and all pneumatic and electrical ____________ are properly mated.
2. Troubleshooting charts in flight-line technical orders are usually listed in ____________ order.
3. A troubleshooting table gives you a list of malfunctions, ____________ procedures, ____________, and ____________ action.
4. In a troubleshooting table, the procedure column contains a series of steps with a ____________ ____________ column which directs you to the ____________ isolation.
5. When checking continuity, check for the following: ____________ electrical connectors; connectors; ____________ or ____________ pins; continuity between specified ____________; proper ____________; and shorts to ____________ and between wires.
6. After a repair or maintenance action, the ADC system requries a(n) ____________ ____________ and the test equipment required is a(n) ____________ test set.

A47. Identify the test equipment required for bench checking the CADC.

Test Equipment. The test set for supplying pneumatic pressures to the CADC in the shop is the TTU-205.

The test sets used in the shop are the AN/ASM-270A or AN/ASM-201B. These test sets are used for functional checks of computers and for precision calibration of modules in the computer.

The basic AN/ASM-270A has the following components; computer holder, computer test set, pneumatic manifold, module holder, dynamometer decade resistor box, cable assembly, pneumatic hoses, protractor, two toolkits, true airspeed tester, and a pneumatic regulator.

Now, we will list the equipment required to test the CADC that is not supplied with the AN/ASM-270A. This equipment consists of an oscilloscope, an insulation test set, a multimeter, an electronic multimeter, a special air cabinet, an air data test set, a workbench, and an altitude encoder test set.

The basic AN/ASM-201B has the following components: computer holder, VTVM, computer test set, two toolkits, dynamometer, test bench, cable assembly, protractor, module holder, rudder pad, pneumatic tester SPC module, rubber pad, hi-pressure pneumatic hose, regulator pneumatic hoses, pneumatic manifold instrument display cable assembly, pneumatic regulator, and an extra testbench.

The equipment required for testing the CADC, but not supplied with the tester is as follows: oscilloscope, stopwatch, TTU-205 pressure temperature test set, and an altitude encoder test set.

Exercises (A47):

1. Identify the test set used for supplying pneumatic pressures to the CADC in the shop.

2. Identify the test sets used to functionally check a CADC.

A48. Determine bench check requirements of the CADC.

Bench Check. You should know and understand bench check procedures, because CADCs that are issued new from supply need to be functionally checked on the testbench before being installed in the aircraft.

Also, if you are working on the CADC system on the aircraft and the results of your troubleshooting indicates a problem malfunction of the CADC, it needs to be removed and brought to the shop for bench check.

You may be assigned to the shop repair section, where you are required to bench check and repair CADCs. If this is so, you need to have a thorough understanding of the operation of the CADC and the application of the applicable shop test equipment.

As field-level maintenance, you are limited to making adjustments of adjustment points and removing and replacing defective modules. The defective modules are then sent to the depot for overhaul.

Bench checking of the ADC system also consists of checking the operation of the ADC system indicators. The ADC indicators are all sealed indicators. If they do not operate properly or within tolerance, they need to be sent to depot level maintenance for overhaul.

Before beginning a bench check, obtain the correct technical order for the equipment you are going to bench check. The technical order will list the required test equipment, the procedures for connecting it, and step-by-step bench check procedures.

It is beyond the scope of this CDC to give step-by-step bench check procedures. Modifications of equipment causes a continued change in technical information, so before complying with a bench check, obtain the applicable current TO and follow its step-by-step procedures.

Exercises (A48):

1. When would you need to functionally check a CADC?

2. What repair are you authorized to perform at field-level maintenance?

Navigation Systems

THE NEXT GROUP of flight instruments discussed in this volume utilize gyroscopes as their principal sensing devices. Within this group are the directional gyro and the attitude indicators and systems. Since gyroscopes are used as the sensing devices for these flight instruments, you should have a good understanding of gyroscopic principles.

3-1. Gyroscopic Principles

Now, we will review the gyroscopic principles. We will then discuss some fundamental gyro characteristics.

A49. Differentiate between a universally and a semiuniversally mounted gyroscope and describe gyroscopic characteristics.

Gyro Characteristics. A gyro (gyroscope) is simply an accurately balanced, spinning flywheel (rotor). The rotor, shown in detail A of figure 3-1, spins about its central spin axis (x) which passed through its center of gravity. The spinning rotor is mounted in supports (gimbal rings) so that it is free to rotate and turn or tilt in any direction about its center of gravity. The gimbal ring, shown in detail B of the figure, supports the spin axis of the rotor. This gimbal ring is referred to as the inner gimbal when it is mounted inside another gimbal ring (outer gimbal), as shown in detail C. The outer gimbal ring can be mounted in still another gimbal ring or frame, as shown in detail D. When the gyro rotor is mounted, as shown in detail D, the gyro is said to have 3° of freedom (movement).

Degrees of freedom of a gyro refers to the axis about which the gyro is free to move. For example, imagine for a moment that the inner gimbal, shown in detail B of figure 3-1, is fixed. The only movement possible for the rotor is to rotate about the spin axis. The gyro is said to have one plane of freedom. Now let's mount the gimbal inside another gimbal, as shown in detail C. Imagine now, the outer gimbal of detail C is fixed and the inner gimbal is pivoted at the Y axis. Now the rotor can rotate about the spin axis X and the rotor and inner gimbal assembly can tilt or rotate about the Y axis. This gyro has 2° of freedom and is said to be semiuniversally mounted. Now imagine that the rotor and two gimbals are mounted in a frame, as shown in detail D. You can see that the complete assembly is now free to rotate about the Z axis. This gives the gyro 3° of freedom. The gyro then is said to be universally mounted. The practical applications of gyros in flight instruments are based upon two fundamental gyro characteristics: gyroscopic rigidity and precession.

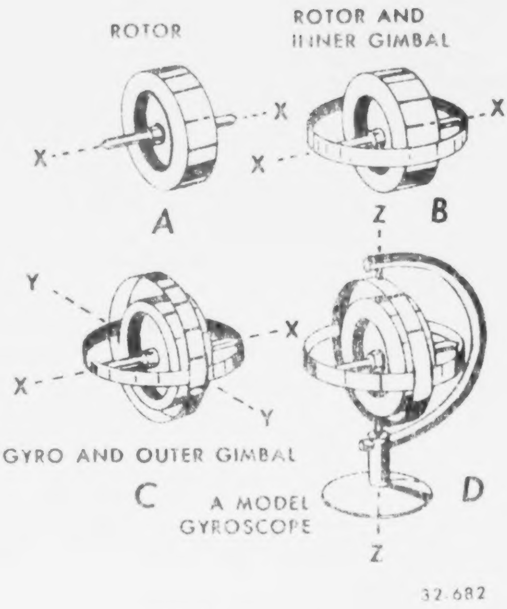

Figure 3-1. Elements of a gyro.

Rigidity. One of the two fundamental characteristics of the gyroscope is rigidity. Gyroscopic rigidity is the tendency of any rotating body to maintain a fixed position in space. This characteristic is the result of the action of forces which affect the state of rest and motion of a gyro. Newton's first law of motion states that a body continues in its state of rest or of uniform motion. It will remain in a straight line unless it is compelled by outside forces to change that state. In accordance with this law, a rotating wheel tends to maintain its plane of rotation in space and, consequently, the position of its spin axis.

Three factors determine a gyroscope's strength, or amount of rigidity; the weight of its wheel, or rotor; the distribution of its weight; and the speed at which the rotor spins. Thus, rigidity may be increased by adding to the weight of the rotor. It remains fixed in its original position even if the aircraft rolls, pitches, and yaws. A gyro with a heavy rotor has more rigidity than one with a light rotor if their speeds are exactly the same. Increased rigidity may be obtained by distributing the weight of the gyro to the outer rim of the rotor. The outer rim should be as far from the spin axis as possible without increasing the weight of the rotor. Rigidity is also increased if the speed of the rotor is increased. A slowly spinning rotor gives the gyro little or no rigidity.

Apparent precession (drift). Rigidity fixes the gyro's spin axis in space (the axis will point in a fixed direction), the rotating earth turns under the gyro. The axis of the gyro appears to tilt. A gyro whose axis is vertical at 6 o'clock in the morning, appears to be horizontal at noon. The gyro appears to be upside down at 6 o'clock on the evening. This creates the illusion that the gyro has turned over end for end. A complete revolution will be made every 24 hours. Actually, however, the gyro has maintained its position in space, and the earth has moved around it. This movement of the earth in relation to gyro is called apparent precession.

The apparent precession of the gyro makes it unfit for use as a reference over an extended period of time. For this reason it should have some type of compensating or correcting mechanism. Over a relatively short period of time, however, a gyro may be used to establish a satisfactory reference.

Induced precession. Remember that in apparent precession the earth moves in relation to the gyro. However, the gyro may be made to move in relation to the earth. This motion is called precession.

The rigidity of the gyro resists any force applied which would tip its axis in any direction. When enough of a tipping force is applied to overcome this rigidity, the spin axis will move, but not in the direction of the force as would be expected. Instead the axis moves at a right angle to the applied force in the direction of the gyro's rotation. This peculiar action is called gyroscopic precession and may be exhibited by a rolling hoop. If we wish to change the hoop's direction of travel, we do not press against the rim at the front or back, but at the top, as if we intended to tip it over about an imaginary horizontal axis. The hoop resists this pressure and turns about a vertical axis.

Precession takes place when a force is applied to the gyro horizontal axis. It will be found that the applied pressure meets with resistance and the gyro turns or precesses about its vertical axis. Figure 3-1 illustrates the effect of precession on the gyroscope. Detail A shows that a weight is about to be placed on the inner gimbal which applies a force to the gyro's horizontal axis. If the rotor were not spinning, the weight would cause this point to tilt down. Because the rotor is spinning the gyro has rigidity. The force applied by the weight, as shown in detail B, is resisted by the gyro. When the weight is placed on the gimbal, it exerts a downward pressure. This pressure has the same effect as applying pressure to the bottom of the rotor rim. However, because of the gyroscopic principle of precession, the reaction of the force is 90° away from the applied force in the direction of rotor rotation. The interaction of the applied force and the rigidity principle causes the gyro assembly to turn, as shown in detail C. If the rotor were spinning in the opposite direction, the gyro assembly would have turned clockwise as viewed from above.

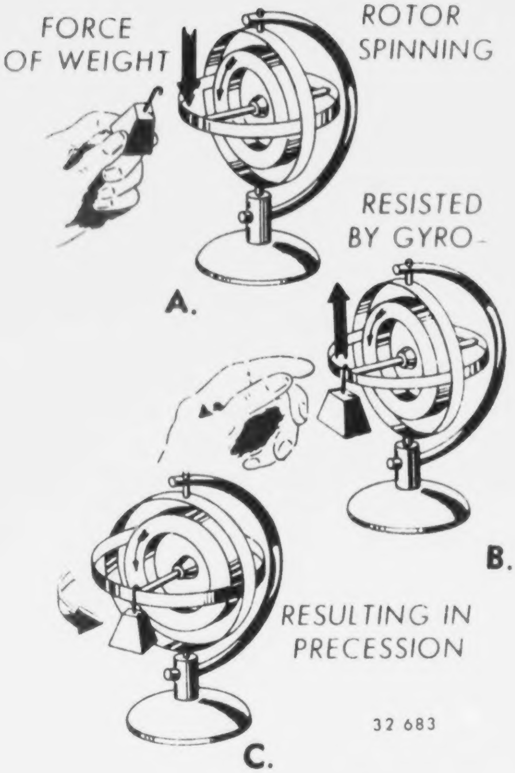

Figure 3-2. Gyroscopic precession.

In the figure you see what happens if you try to tilt a spinning gyro. Keeping this in mind, let's see what will happen if we try to turn it. If you apply a force to the outer gimbal 90° away in the direction of rotation, the gyro will tilt. So as you can see, if you try to tilt the gyro it will turn. If you try to turn the gyro, it will tilt. This principle is used in the erection system which we will discuss next.

The gyros in the instruments used in aircraft are designed to remain in a definite position in relation to the earth's surface. They are provided with an erection system which enables them to counteract both the apparent precession and induced precession. This erection system keeps the gyro in a fixed position in relation to the earth's surface. This is done by applying a force in the right place to cause the gyro to precess. The erection system used in our instruments can result from a stream of air, the movement of a ball, or the action of a torque motor. The operation of the erection system will be given as each instrument is covered.

Exercises (A49):

1. What is the difference between a semiuniversally mounted and a universally mounted gyroscope?

2. What is meant by the word "rigidity"?

3. Explain briefly apparent precession.

4. What is it called when a gyro is made to move in relation to the earth?

5. How does a spinning gyro react to a force applied to its horizontal axis?

6. What counteracts both the apparent and induced precession of a universally mounted gyro?

A50. Cite purpose and operation of the directional gyro.

Directional Gyro. In this objective we shall focus our attention on the directional gyro and how it makes use of the gyro principles we have covered. The directional gyro measures, in degrees, the amount of an aircraft turn.

The directional gyro does not replace the compass, for it does not have the proper sensing element to indicate the magnetic heading of the aircraft. The pilot must read the correct heading from a compass system and then set the directional gyro. Unlike the compass, however, the directional gyro is not affected by the centrifugal force of turns, by rough air, by magnetic disturbances, or by the attitude of the aircraft (within the limits of the gyro. This freedom from disturbing influences enables the directional gyro to provide more accurate readings than the compass provides under similar adverse conditions.

To obtain its best accuracy, the directional gyro must be reset every 15 minutes. The increments recorded on its specially prepared azimuth card may represent objects on the horizon which the pilot has selected as references. These increments actually provide for more accurate flying by instructions than can be obtained by visual observation of terrain, landmarks, etc.

The increments on the gyro card are not indicated by directions, but rather in degrees of azimuth. Because the word "azimuth" is used to represent headings in this course, remember that it refers to the direction in which the aircraft is pointed.

We will discuss a typical directional gyro. The dial is marked in 5° increments, with the numerals placed at 30° intervals. A pointer indicates the heading. Index marks at the edge of the dial are used for easy reference when making 45°, 90°, and 180° turns. A flag marked "OFF," located at the upper right side of the dial, comes into view when no power is getting to the gyro. There is a knob at the lower left, marked "POINTER." It allows you to set the pointer at any desired heading. There is a knob on the lower right, marked "DIAL AND POINTER." It allows you to turn both the pointer and the dial to one of the index marks for easy refrence. To move the pointer or the dial and pointer, you must depress the respective knob. When either the pointer or dial and pointer are disengaged from the bevel gear, a "CAGED" flag appears at the bottom of the dial.

The rotor of the instrument is the revolving part of a three-phase induction motor. It is energized by 115-volt, 400-Hz, three-phase power and spins the gyro at approximately 22,000 rpm. In this indicator, the gyro's spin axis is horizontal in reference to the earth's surface. The inner gimbal is mounted on bearings in the outer gimbal so that it also turns about a horizontal axis. The outer gimbal is free to turn about a vertical axis attached to the instrument case. This gives the gyro 3° of freedom; so, the instrument is a universally mounted gyro.

The instant the gyro starts to operate, it has a tendency to vibrate until the rotor reaches full speed. Naturally, this action causes excessive wear on the gyro bearings. A brake is applied to the outer gimbal until the gyro becomes stable enough to prevent this damage. The brake is a disc and a two-strip bimetallic spring. Resistance wire is wound around one strip of the spring. When the wire is not energized, the disc presses against the top of the gimbal. When power is turned on, the resistance wire heats up (45 seconds) and causes the bemetallic spring to bend, so that it pulls the disc away from the gimbal. By the time the brake is completely released (45 seconds), the gyro has attained enough speed to remain rigid in space. When the instrument is turned off, the gyro loses speed. Before it loses enough speed to start to wobble, the resistance wire on the brake again has time to cool and the brake falls on the gimbal. This prevents excessive wear on the bearings.

The aircraft actually turns around the gyro assembly rather than the assembly around the aircraft. The pointer moves to indicate the number of degrees of turn. The gyro assembly is connected to the pointer through two large bevel gears and a magnetic coupling. One gear is horizontal and is part of the outer gimbal. The outer gear is mounted vertically behind the pointer. A magnetic housing is attached to the vertical level gear. The pointer is attached to the magnet which is free to rotate within the magnet housing. Such an arrangement allows the pointer and magnet to be disengaged from the bevel gears and set manually to the desired heading by pushing the caging knob in and turning it.

Exercises (A50):

1. How often should the directional gyro be reset to obtain its best accuracy?

2. What is the purpose of the brake in the directional gyro?

3. How is the gyro connected to the pointer?

A51. Describe the purpose of the low-inertia motor in the directional gyro.

Power flag circuit. A low-inertia motor is connected in series with the gyro A- and C-phase windings. When power is applied, the low-inertia motor winds a spring and pulls the POWER OFF alarm flag out of view. The alarm flag, being out of view, tells the pilot that all three phases of power are present and in proper phase sequence. If one or more phases of power are lost to the directional gyro, the low-inertia motor loses its torquing action. The spring unwinds and causes the alarm flag to appear. Also, if improper phase sequence is applied to the gyro, the low-inertia motor drives in the opposite direction, causing the alarm flag to remain in view. If the alarm flag is in view, the pilot knows that the information on the indicator is unreliable.

Exercise (A51):

1. Describe the purpose of the low-inertia motor that is in series with A- and C-phase windings.

A52. Identify the major portions of the erection system and its operations and characteristics.

Erection system. There are three major portions of the erection system. These are the torquer, the pendulum brush assembly, and the amplifier section.

The erection torquer is a motor which has its three windings mounted under the outer gimbal. Two of the windings are always energized. The torque applied causes precession around the horizontal axis in one direction. If the third winding is energized, the torque is applied in the opposite direction, causing opposite precession.

The pendulum brush assembly consists of a pendulum attached to a brush. The brush rides against a pivot which is an extension of the gyro horizontal axis. This pivot is half steel and half glass. Only the steel half is capable of acting as a conductor. The pendulum is mounted so that it is always perpendicular to the earth, within the operating limits of the gyro.

The amplifier section is located at the rear of the instrument. Some directional gyros do not include it and have the power fed directly to the pendulum brush. The typical directional gyro uses the amplifier section to reduce the amount of current going to the brush. This insures the application of a more even signal.

Two gas-filled tetrode tubes are used in the amplifier section. These tubes act as an electronic switch for energizing the third phase of the torque motor. Both tubes are operated well below their capacity. One of

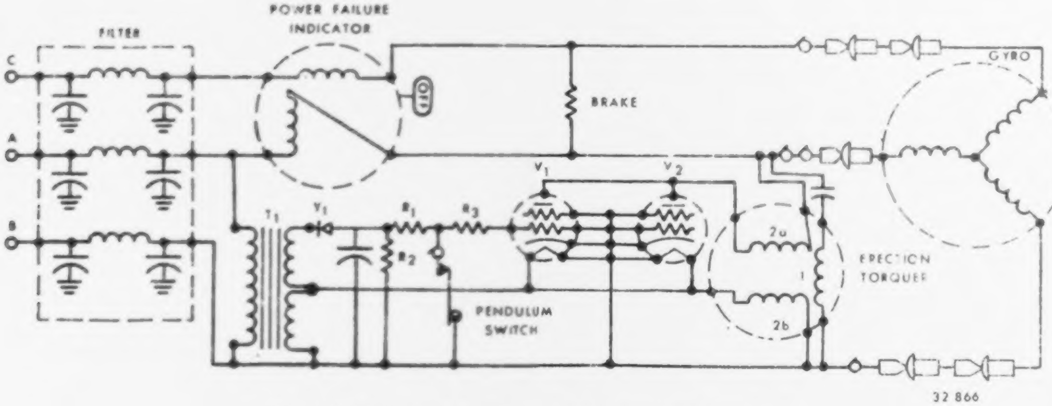

Figure 3-3. Wiring diagram of a typical directional gyro.

these tubes can keep the instrument operating normally if something goes wrong with the other. In addition to the tubes, a rectifier provides DC voltage. The DC voltage is applied to the tetrodes as grid bias.

The final unit of the amplifier section is the transformer. The transformer supplies voltage for the vacuum tube heaters and to both windings of the erection torquer. It also supplies the voltage which is rectified for use as grid bias.

Now let's see how the erection system operates in conjunction with the gyro. Figure 3-3 is a diagram of the three-phase erection torquer. Two of these phases are constantly energized. The third phase is energized only when tubes V_1 and V_2 conduct. Next, we find three resistors (R_1, R_2, and R_3). Resistor R_2 provides the required grid bias. Resistor R_1 removes the bias from V_1 and V_2. Resistor R_3 is a grid resistor. A rectifier (Y_1), a transformer (T_1), and a pendulum switch complete the system. Power is applied from A, B, and C through the filter unit. The filter eliminates interference with the radio equipment. From the filter, power passes to the power failure motor (low-inertia motor), the brake, the T_1, and phases 1 and 2b of the erection torquer.

Let's suppose that the gyro has moved out of the level position so that the pendulum brush rests on the nonconducting section of the pivot. Since the rectifier (Y_1) allows current to flow only when the top of the secondary winding of T_1 is negative with respect to the center tap, a highly negative bias is placed on the control grids of V_1 and V_2, putting them at cutoff. Under these conditions, two windings of the erection torquer are energized, the torque is applied to the outer gimbal. This causes the gyro to precess toward the level position.

When the gyro precesses beyond the level position, the pendulum brush again comes in contact with the pivot, but this time with the conducting side. The contact provides another path through R1 and the pendulum brush for current to flow. This effect removes the negative bias on the grids of the tubes and allows them to conduct. When this happens, phase 2a of the torquer is energized to produce an opposing torque. This torque causes the gyro to reverse its direction of precession. Again, as the gyro moves past the level position, the pendulum brush contacts the nonconduction side of the pivot. The tubes become biased at cutoff. In other words, during actual operation, the erection system keeps the gyro constantly precessing back and forth about the level position. However, the mount of the precession is so small that, for all practical purposes, the gyro is considered to be in the horizontal position.

This, then, is how the directional gyro operates. Next, let's consider your responsibility, as a specialist, to keep the instrument operating.

Exercises (A52):

1. Identify the three major portions of the erection system.

2. The erection torquer mounted under the outer gimbal causes a precession around what axis?

3. On the pendulum brush assembly, how is the pendulum always mounted?

4. Refer to figure 3-3. How does an open plate circuit in V_1 affect the operation of the gyro? Why?

A52. Describe directional gyro inspection and maintenance procedures.

Inspection. In addition to the routine inspection, you check the operation of the pointer (left knob) and the dial and pointer (right knob). When you check the pointer, push in the left knob and turn. Observe the movement of the pointer and make sure it is free from binding throughout 360° of the azimuth dial. Repeat the same procedure with the pointer and dial (right knob). The cage flag appears when either knob is pushed.

Maintenance. When you have established the serviceability of the gyro and installed it in the aircraft, perform an operational check on the system. Apply power to the gyrp and observe that the power-off flag disappears. This insures that the required three-phase power, with the proper phase sequence, is applied to the gyro.

The directional gyro is a hermetically sealed instrument and no internal maintenance can be performed at field level; however, routine maintenance is performed. Routine maintenance consists of such things as wiring continuity checks, wiring repairs, and component replacement. When installing electrical components, refer to the applicable TO for correct electrical connections. When you replace any circuit component, perform an operational checkout to insure satisfactory operation.

Exercises (A53):

1. What additional item must you check when inspecting a directional gyro?

2. What maintenance is performed on a directional gyro at field-level maintenance?

A54. Identify the directional gyro bench test equipment and cite what you are checking for when you tilt the gyro.

Troubleshooting. When you perform an operational check and the power-off flag remains in view, you must troubleshoot the system. Before you apply power, make sure that the applicable circuit breakers are set. If a circuit breaker opens after you apply power, you must find and correct the trouble before you reset the circuit breaker again. Refer to the applicable TO for voltage and continuity checks on the system wiring. Before you replace a suspected component, make sure that the associated wiring is not defective.

Test Equipment. The only test equipment required to bench check the operational gyro is an oscillating tilt table and an instrument test adapter. The oscillating tilt table tilts 7.5° in all directions; it oscillates at a rate of five to seven times per minute.

Bench check. You must perform a bench check, using the applicable TO, on the directional gyro. This is done in order to determine the serviceability of the indicator. The gyro is bench checked prior to installing it on the aircraft. Also, if you suspect an indicator malfunction while troubleshooting, you perform a bench check on the indicator for serviceability before you send the gyro to depot for overhaul. The two tests described in this section are those commonly used in a field maintenance shop. Since you must consult the individual TO when you are making any bench test, we give only short general descriptions of the test.

To check the balance of the rotor, place the gyro in a test fixture and connect it to a power source. When the proper speed has been attained, tilt the indicator 15° to the right and rotate it until the pointer indicates 45°. Operate the indicator for 15 minutes and note the drift. Then, repeat the test, tilting the instrument to the left, and again note the drift. The amount of allowable drift and the tolerance can be found in the applicable TO.

For this second test involving roll, pitch, and yaw, you use the oscillating tilt table. Apply power to the gyro before placing the instrument on the tilt table. Then, uncage it on the 0° heading and start the oscillating unit of the table. Let the table operate for 20 minutes while the instrument is at the 0°, 90°, and 270° headings. Check every 5 minutes to observe the drift from the original heading during each of the three 20-minute test periods. The maximum allowable drift and tolerance will be found in the applicable TO. If the indicator does not operate within the tolerance given by the TO for the above tests, you must send it to the depot for overhaul.

Exercises (A54):

1. Identify the test equipment required to bench check a directional gyro.

2. What are you checking for when you tilt the tilt table and check to see if the gyro indicates the same amount of tilt?

3-2. Vertical Gyro Indicators

You have just studied how a gyroscope is used to provide directional heading information. In our next discussion, we will see how a gyro is used to indicate aircraft movement around the longitudinal and horizontal (roll and pitch) axes.

A55. Cite how the electric-driven attitude indicator is mounted and describe the principles of operation.

At one time, the electric-driven attitude indicator was one of the primary flight instruments. Now it is used primarily as a standby instrument for backup attitude information in case the main attitude indicating system fails.

The electric-driven attitude indicator is a self-contained instrument. The gyro, which is mounted with its axis perpendicular to the earth's surface, is the only rotating portion of a three-phase induction motor. It operates on 115-volt, 400-Hz, three-phase power. However, modern technology has produced miniature versions of these indicators that operate on 28-volts DC power.

The gyro has 360° of freedom about the horizontal axis and 360° of motion about the lateral axis. The effective freedom about the lateral axis is attained by means of a controlled precession. This controlling permits the indicator to show the correct attitude of the aircraft, even in an inverted position.

The dial consists of an attitude bar which represents the aircraft, a bank pointer, and a sphere attached to the gyro. On the sphere the two words "CLIMB" and "DIVE" are printed. You determine the aircraft's attitude by observing the position of the attitude bar in relation to the horizon bar. The attitude bar moves with the case, but the horizon bar remains fixed, held by the gyro. In a dive or climb of more than 27°, the horizon bar reaches the extreme position. When one of the words "CLIMB" or "DIVE" intersects the bar, the instrument is indicating approximately 60° of pitch. To read the degree of bank, you merely note the position of the bank pointer in relation to the bank indexes, which appear on a fixed scale on the outer rim of the dial. In this instrument, the power-off flag is operated by a two-phase low-inertia motor. The flag indicates the failure of one phase of AC power.

The gyro in the EDAI is subjected to forces which attempt to tilt it. A simple nonelectric erection system is built into the instrument to counteract the forces. It consists of a round, rotating magnet, a plate made of

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nonmagnetic metal, two steel balls, and a ratchet and pawl escapement mechanism. Two arms, situated on opposite sides of the rotating plate, actually push the balls. The magnet is connected directly to the rotor shaft and revolves with it at about 22,000 rpm. As the magnet rotates, it sets up eddy currents which pull the plate around, but at a greatly reduced speed. The plate's speed of rotation, approximately 48 rpm, is controlled by a ratchet and pawl escapement mechanism, operating on the same principle as the fork and escapement wheel in your watch. It acts as a sort of brake, which alternately holds and releases the driving part of the mechanism. When the gyro is erect, the balls have no effect. However, when the gyro tilts, one-half of the tract will be lowered than the other. So one of the balls will roll toward the low side (the other one being restrained by the arm that pushes it). As this action takes place, a force is applied to the gyro, a force which reacts 90° ahead of each ball, precessing the gyro to the erect position.

Exercises (A55):

1. How is the EDAI gyro mounted?

2. How many degrees of motion does the EDAI have about its lateral axis?

3. What does the attitude bar represent on the EDAI?

4. What is the maximum amount of movement of the horizon bar in climb or dive?

5. What operates the power-off flag in the EDAI?

6. What is the erection mechanism made up of in the EDAI?

3-3. Attitude Reference System

Now that you have some understanding of how gyros are used to obtain directional information relating to the different axes of an aircraft, let's look at how these systems have been improved to provide faster, more accurate and reliable information for all pitch attitudes of the aircraft.

A fighter aircraft must assume some unusual attitudes during offensive and defensive maneuvers. For example, the fighter bomber aircraft that is required to carry nuclear weapons must perform a toss bomb type of maneuver. In this maneuver the aircraft completes one-half of a loop. To do this, the aircraft must travel through 180° of pitch attitude. On completion of the one-half loop, the aircraft heading has changed by 180° and the pilot rolls the aircraft 180°. This half loop and rollout is known as an Immelmann turn. The all-attitude reference system that you will study in this section is designed to indicate aircraft attitude throughout such maneuvers.

Your primary tasks are to make inspections, bench and operational checks, adjustments, and installations. You will also troubleshoot and repair the all-attitude reference system or system components. In this section we shall cover topics that directly related to these tasks. You must first understand the operation of this system's components and its complementary components (compass transmitter and horizontal situation indicator) to perform these tasks to a high degree of professionalism.

We will use an all-attitude reference system to familiarize you with the components and operation of attitude indicating systems and compass systems. Whether they are separate systems or combined into a single system, the basics of each system will be very similar.

A56. State the purpose of the attitude director indicator and the operation of its components.

Attitude Director Indicator. The attitude director indicator (ADI) is an electromechanical instrument that primarily provides a pictorial display of aircraft roll and pitch attitude relative to level flight above the earth. In addition, the integrated pictorial view shows flight director data, rate-of-turn information, and inclinometer orientation. On some aircraft, it may include compass headings; however, we will discuss the compass system separately.

Aircraft roll and pitch attitude is viewed with respect to a servopositioned sphere inside the indicator. An artificial horizon is painted on the sphere; it is referenced to the earth's true horizon by control signals from a vertical gyro. A pointer or needle provides rate-of-turn information and is connected to the output signal from a rate transmitting gyro. If the aircraft power fails, a flag showing the word "OFF" appears to indicate the power failure. The indicator lighting consists of parallel connected bulbs that illuminate the bezel (roll dial) and the sphere.

The attitude director indicator and amplifier are separate. The amplifier can be mounted on the back of the indicator or it can be installed at another location in the aircraft. The power supply section of this amplifier furnishes the necessary voltage for the operation of the units within the indicator.

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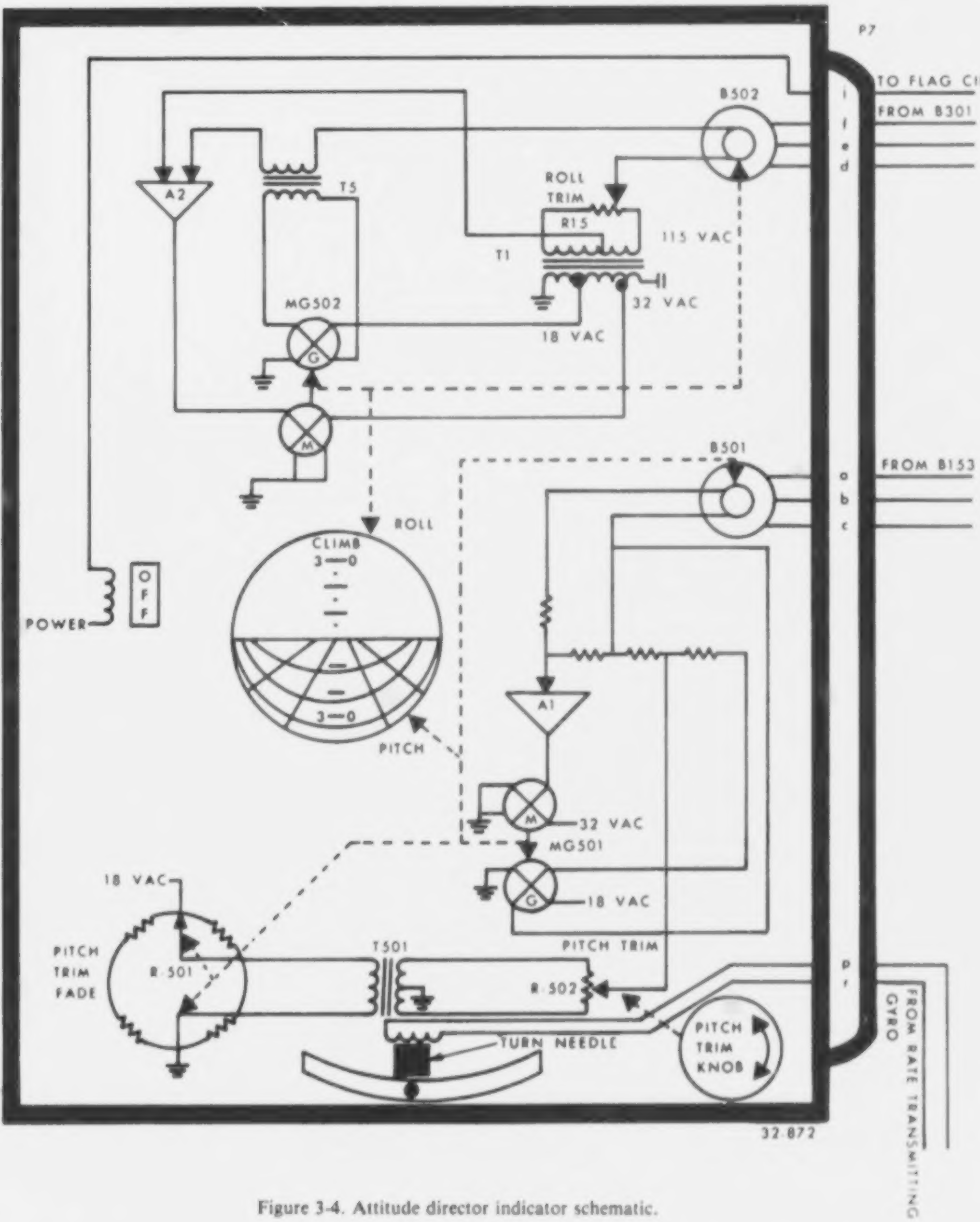

P7
TO FLAG CIRCUIT
FROM B301
B502
i
f
e
d
ROLL TRIM
R15
115 VAC
T5
A2
T1
32 VAC
18 VAC
MG502
G
M
B501
FROM B153
a
b
c
ROLL
CLIMB
3—0
3—0
POWER
OFF
A1
PITCH
32 VAC
MG501
18 VAC
18 VAC
PITCH TRIM FADE
R 501
T501
PITCH TRIM
R 502
p
r
TURN NEEDLE
PITCH TRIM KNOB
FROM RATE TRANSMITTING GYRO
32-872

Figure 3-4. Attitude director indicator schematic.

Pitch information is displayed on the indicator through 360° of attitude with no flip over of the sphere as in the indicator previously covered. This is because the outer roll gimbal prevents gyro upset. The pitch attitude of the aircraft is read from the relation of the miniature aircraft to the sphere. Reference to figure 3-4 will aid you to better understand the ADI operating circuits discussed in the text that follows. A position error signal is fed from B153 in the vertical gyro to the stator windings of control transformer B501 in the indicator. This signal is induced in the rotor of B501 and is then fed into amplifier A1. Although the amplifier is a separate unit, the figure shows the amplifier within the indicator. The resultant signal fed into A1 is amplified and routed to the control phase of MG 501. The motor-generator unit is mounted inside the indicator and is mechanically coupled to the sphere. When the motor is running, it moves the sphere and the rotor of B501 to position the rotor at null with the rotor of B153 in the veritcal gyro.

When the rotor of B501 is at null with B153 in the vertical gyro, no signal is fed to amplifier A1. As a result, no control phase voltage is applied to MG501, so the motor stops. The sphere remains stationary, indicating the existing pitch attitude in climb, or dive, relative to the earth's horizon. The rate generator of MG501 is in the same unit as the servomotor, and the rotor of the generator is mounted on the same shaft as the rotor of the servomotor. As a result of this, when the rotor of the servomotor turns, the rotor of the generator also turns. One phase of the rate generator is energized by AC voltage from the power supply transformer in the amplifier power supply unit. The output phase (damping rate signal) is routed to the amplifier, where it dampens the pitch error signal to prevent overtravel or oscillation of the sphere.

When turned, the pitch trim knob, located in the bottom right corner on the front of the ADI, moves the wiper of the pitch trim control (R502). This action applies a voltage potential to the pitch servoloop to move the sphere, thus compensating for aircraft load conditions. The pitch trim knob, when rotated through its full range of travel, displaces the sphere at least 10° in dive and 5° in climb. When the aircraft exceeds 20° of pitch, the 18-volt AC that is applied to the primary winding of T501 decreases. Consequently, the amount of pitch trim signal from R502 also decreases. When the aircraft reaches 75° of pitch, the pitch trim fade circuit removes all the applied voltage from the primary winding of T501 and there is no signal output from R502. This automatically fades out any preset pitch trim, allowing the pilot to obtain an accurate pitch indication during a bombing maneuver. Pitch trim remains cancelled from 75° to 105° of aircraft pitch.

The ADI roll servoloop controls the indicator sphere in roll attitudes. The roll servoloop functions the same as the pitch servoloop, except that the roll servomotor (MG502) moves the sphere about the indicator's longitudinal axis rather than about the lateral axis. The roll (bank) pointer is attached to the sphere housing (yoke). It is read against the bank-angle fixed scale located on the bezel attached to the indicator case. The bezel (dial) is marked in increments of 10° from 0° to 30° and in increments of 30° from 30° to 90°, right and left bank.

The roll trim control (R15) is a potentiometer located on the ADI amplifier and can be adjusted by turning a screw. This adjustment removes slight roll position errors during the installation of a new indicator. However, before you make this adjustment, be sure that the aircraft and gyro are level.

An inclinometer or turn-and-slip indicator is mounted in the bezel below the indicator sphere. Aircraft slip and skid is indicated by the movement of the black ball inside the inclinometer tube. Fluid in the curved tube serves to dampen out vibrations between the ball and tube to insure smooth, accurate movement of the ball. The glass tube has an extension at one end to permit expansion of the fluid. When the aircraft is flying straight and level, the ball is kept centered in the tube by its own weight. When the aircraft is yawing or making a turn, the forces of gravity and centrifugal force act upon the ball. During a coordinated turn, both forces are such that they hold the ball centered in the tube. When gravity and centrifugal forces become unbalanced, the ball moves away from center to indicate an uncoordinated turn, a skid, or slip.

In a skid, the rate of turn is too large for the angle of bank. The excessive centrifugal force causes the ball to move to the outside of the turn. In a slip, the rate of turn is too slow for the angle of bank. The lack of centrifugal force causes the ball to move to the inside of the turn.

A rate-of-turn indicator is mounted below the indicator sphere. A small horizontal pointer that moves beneath a horizontal scale displays the rate of aircraft turn in degrees per minute. The rate-of-turn signal is produced in a rate transmitting gyro, and the signal is applied directly to the indicator.

Exercises (A56):

1. In the all-attitude reference system, what is the function of the attitude director indicator (ADI)?

2. The rate-of-turn signal in the ADI is received from what unit (component)?

3. The attitude director indicator's amplifier is a separate unit from the indicator and may be located where?

4. What prevents the sphere in the indicator from flipping when the aircraft goes through a 360° pitch maneuver?

5. The pitch trim knob on the ADI will cause the sphere to be displaced approximately how many degrees in dive and climb?

6. What should be checked before making a roll position error adjustment on a newly installed indicator?

A57. Describe the purpose and operation of the rate gyroscope transmitter.

Rate Transmitting Gyroscope. The rate gyroscope transmitter is a remote rate gyro. The purpose of this gyro is to provide the pilot bank control information which is displayed in the ADI. The gyro senses the direction and rate of turn, develops a signal, and transmits

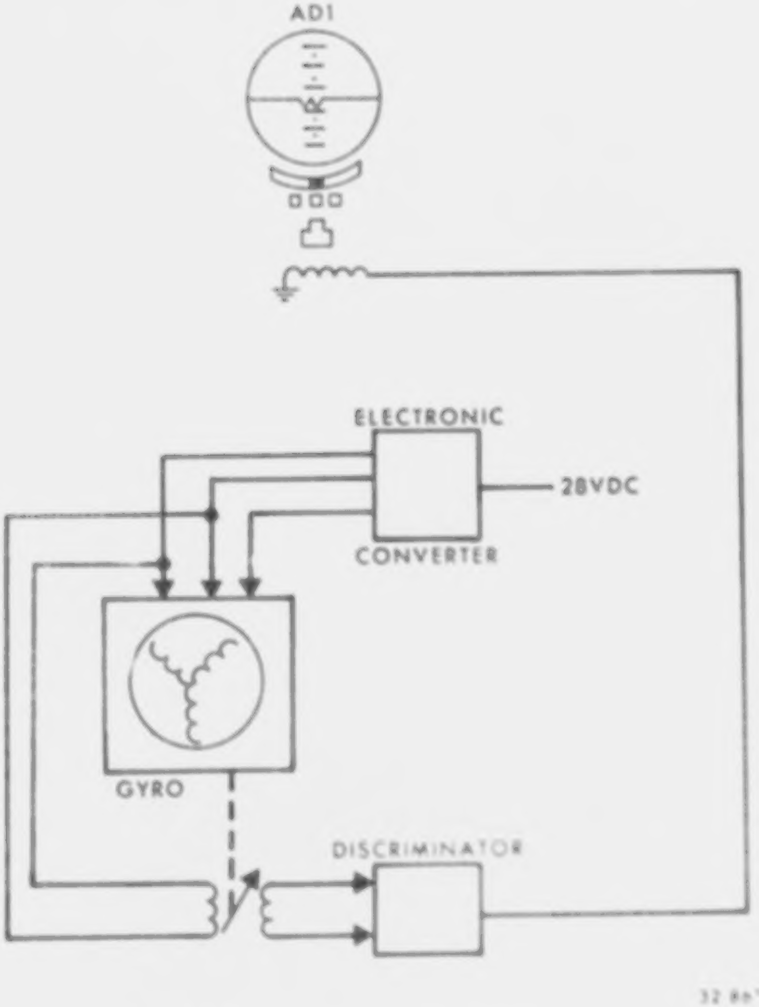


Figure 3-5. Rate gyroscope transmitter schematic.

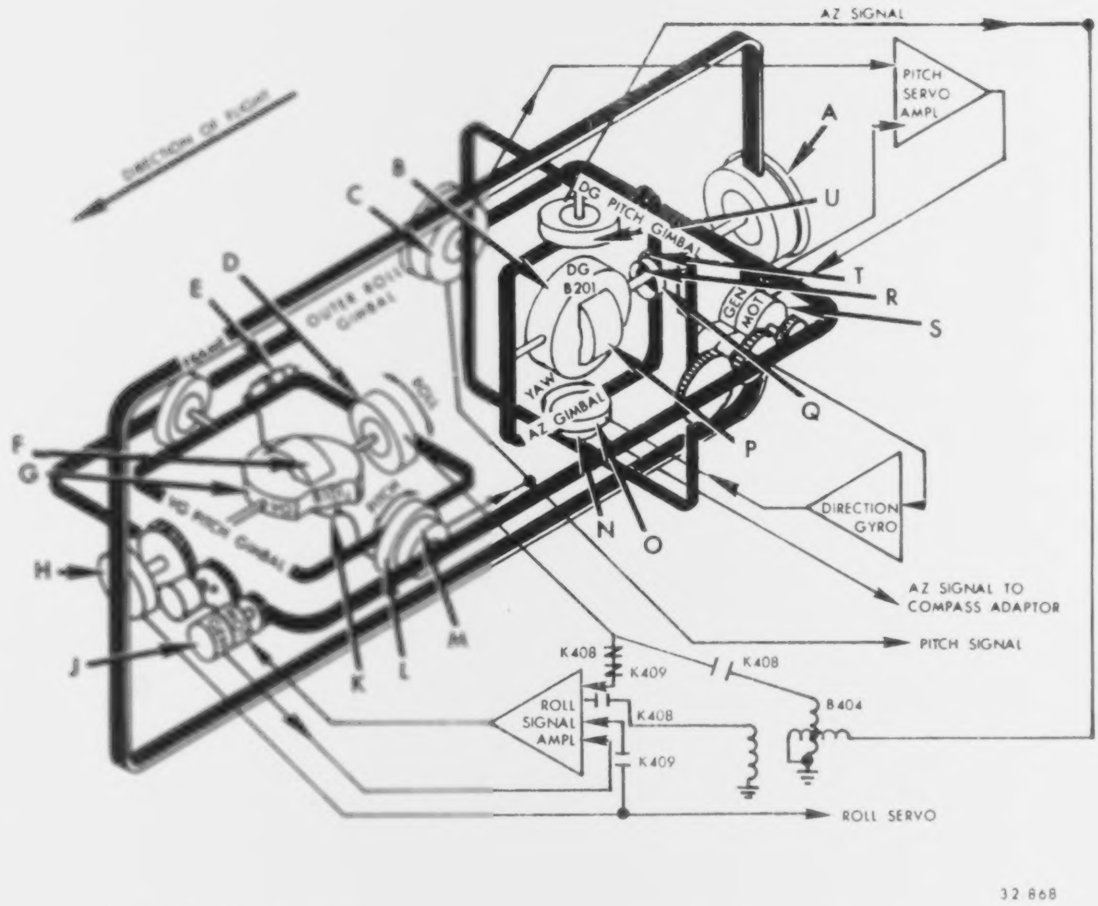
the signal to the meter movement in the ADI. The rate-of-turn pointer (meter movement in the ADI) indicates the aircraft rate of turn about the yaw axis in degrees per second. Needle deflection, one needle width to either side of center, indicates a turn rate of 1½° per second or 360° in 4 minutes. When the needle is aligned with the outer marking on the dial, double needle width, the turn rate is 3° per second or 360° in 2 minutes.

Notice in figure 3-5 that the power requirment for this component is 28 volts DC. This DC is applied to an electronic converter and changed to AC. From the converter, the AC is applied to the gyro windings and a variable transformer. When the aircraft is in straight flight, the transformer is in a position so that no voltage is induced into the secondary winding. However, when the aircraft makes a turn, a signal voltage is induced into the secondary winding because the gyro gimbal is mechanically connected to the transformer. The phasing of the induced signal is determined by the direction in which the aircraft turns. This signal is directly proportional to the aircraft rate of turn and is applied to the discriminator. In the discriminator, the signal is changed to DC and applied to the meter movement in the attitude direcor indicator.

Exercises (A57):

1. What is the purpose of the rate gyroscope transmitter?

2. What determines the phasing of the signal induced into the transformer secondary?


AZ SIGNAL
PITCH SERVO AMPL
A
DIRECTION OF FLIGHT
B
C
U
DG PITCH GIMBAL
DG B201
T
R
S
GEN MOT
D
E
OUTER ROLL GIMBAL
ROLL
YAW
AZ GIMBAL
Q
F
G
VG PITCH GIMBAL
PITCH
P
DIRECTION GYRO
H
N
O
AZ SIGNAL TO COMPASS ADAPTOR
PITCH SIGNAL
M
K408
K409
K408
J
K
L
ROLL SIGNAL AMPL
K408
B404
K409
ROLL SERVO
32 868

A. Roll phase reversing SW 305
B. Leveling gimbal
C. Pitch synchro CX B251
D. Inner roll synchro CX B103
E. Electrolytic switch S105
F. Pitch torquer B102
G. Inner roll gimbal
H. Outer roll synchro CX B301
J. Roll motor generator MG324
K. Electrolytic switch S104
L. Roll torquer B306
M. Synchro CX B153
N. Azimuth CX B 221 (top)
O. Leveling torquer
P. Slaving torquer motor B210
Q. Leveling pickoff
R. Bulb
S. Pitch followup motor generator MG307
T. Photocell
U. Azimuth CX B222

Figure 3-6. Functional block diagram for displacement gyroscope and associated servoloops.

458. State the purpose of the displacement gyro package and its components, and describe its pitch operation.

Displacement Gyro Package. The displacement gyro package contains a vertical gyro and a directional gyro. The vertical is mounted to the front of the gyro package. The directional gyro is mounted to the rear of the gyro package. These two gyros are mounted inside a common gimbal called an outer roll gimbal, as shown in figure 3-6. Because the two gyros are mounted inside a common gimbal, the gyro package provides accurate roll and pitch signals. These signals are transmitted to the attitude indicator throughout 360° of aircraft roll and pitch attitude.

Now let's take a look at the way the gyros are connected together inside the outer roll gimbal. Notice the different axes (roll, pitch, and yaw) indicated in the figure. The vertical gyro is erected in both pitch and roll axes by the pitch torquer (B102, item F) and the roll torquer (B306, item L). The pitch torquer is controlled by an electrolytic switch (S-105, item E) located on the vertical gyro pitch gimbal. This torquer corrects for gyro drift in the pitch axis. The roll torquer is controlled by another electrolytic switch (S104, item K) located on the veritcal gyro housing. Switch S104 senses gyro drift in the inner roll axis at the inner roll gimbal (item G). This erection system keeps the vertical gyro on a spin axis vertical to the earth's surface. The erection system for this vertical gyro operates like the erection system covered in the previous chapter. Also the directional

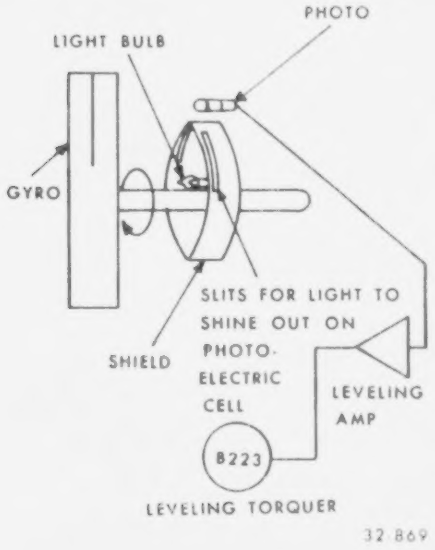


Figure 3-7. Directional gyro leveling.

gyro is kept level on its leveling gimbal (item B) by a leveling torquer (B223, item O) in a spin axis horizontal to the earth's surface. The leveling torquer is controlled by the photocell (item T) which is activated by the bulb (item R) through a leveling pickoff (item Q), as shown in the figure. Let's take a closer look at this unique leveling device by referring to figure 3-7.

Let's assume that the directional gyro drifts and moves in the direction of the arrow just to the right of the gyro. This moves the slit in the shield directly under the photocell. A beam of light hits the cell and produces a voltage. This voltage is amplified and used to operate the leveling torquer (B223) to level the directional gyro. This type of leveling device has an important advantage over the electrolytic switch. The electrolytic switch is affected by centrifugal force; the photocell is not.

Another unique device in this directional gyro is the bearing drive motor. This device eliminates most of the bearing friction. The bearings are rocked back and forth by a bearing drive motor. The motor drives constantly in one direction, moving the drums which are mechanically connected to the bearings. When the spring becomes tight, the gears separate. The spring unwinds, turning the drums in the opposite direction. This back-and-forth movement of the gimbal bearing races reduces bearing friction. Now, back to figure 3-6.

Pitch. When the pitch attitude of the aircraft changes, a pitch signal is sensed by synchro CX B153 (item M). It is located between the vertical gyro pitch gimbal and the outer roll gimbal. This signal is applied to the stators of pitch synchro CT B251 (item C) located on the outer roll gimbal. Also, the pitch signal is used in the attitude director indicator (ADI) and the CPU/4 computer (flight director).

The vertical gyro pitch gimbal stays parallel to the earth's surface because it it attached to the vertical gyro. The directional gyro pitch gimbal stays perpendicular to the earth's surface, but it must be controlled because it is not attached to the gyro. Therefore, the pitch signal from the vertical gyro controls the position of the directional gyro pitch gimbal. As the aircraft pitches up or down, the vertical gyro remains fixed. The stator assumes a new position in relation to the rotor because the stator is attached to the outer roll gimbal. The outer roll gimbal, shown in the figure, reacts the same as the aircraft in the pitch axis. Consequently, the outer roll gimbal rotates around the vertical gyro pitch gimbal in the pitch axis. This provides an accurate pitch signal throughout 360° of aircraft pitch attitude. The pitch signal produced in B153 (item M) is applied to B251 (item C). The output from B251 is applied to the pitch seroamplifier in the amplifier power supply. The output from this amplifier is sent to the control phase winding of pitch follow-up motor generator unit MG 307 (item S) located in the gyro package shown in the figure. As the aircraft changes in pitch, the change between the rotor and stator of B251 is at the same rate as the change between the rotor and stator of B153. Consequently, the directional gyro pitch gimbal stays perpendicular to the surface of the earth so that it maintains a position where an accurate roll or azimuth signal output reference can be sensed. We will explain the operation of the directional gyro after we cover the gyro package.

Exercises (A58):

1. In the all-attitude reference system, the displacement gyro serves what purposes?

2. What two gyros are inside the displacement gyro package?

3. What is accomplished by mounting the two gyros inside the outer roll gimbal?

4. The movement around what two axes is sensed by the vertical gyro?

5. In the directional gyro, a drift in the horizontal spin axis of the gyro is sensed by what unit?

6. What is the function of the bearing drive motor in the displacement gyro?

7. Since the pitch gimbal of the directional gyro is not directly connected to the gyro, how is this gimbal held perpendicular to the earth's surface?

8. Since a gyro remains fixed in space (the same relation as compared to the earth's surface), how is a signal produced in the system when the aircraft goes through a maneuver?

A59. State the purpose of the vertical gyro and determine the operation of the displacement gyro when the aircraft is rolling.

Roll. The roll signal is sensed by the synchro CX B301 (item H) located between the aircraft frame and the outer roll gimbal. This signal is applied to the attitude director indicator and CPU/4 computer. This signal locks the outer roll gimbal perpendicular to the gyro package frame for the first 60 seconds of system operation.

As you should recall, the vertical gyro controls the position of the vertical gyro pitch gimbal. An accurate pitch signal is sensed at B153 (item M) through 360° of aircraft pitch attitude.

The outer roll gimbal is controlled by one of three servomechanisms. The servomechanism that controls the outer roll gimbal is determined by the operation relays K408 and K409. The contacts of these relays are shown in the deenergized position. During the first 60 seconds of system operation, K408 is deenergizeed and K409 is energized. The outer roll gimbal is controlled by servomechanism B301 (item H). The excitation voltage of the rotor induces a voltage into the stators of synchro B301. This induced voltage is routed through the contacts of K409 and applied to the roll amplifier. The output from the roll amplifier drives MG334 (item J), until the rotor of B301 is in a position where the algebraic sum of the induced voltage for this circuit equals zero. This operation positions the outer roll gimbal level with the aircraft wings, no matter what position the aircraft is in. The attitude-director indicator shows 0° roll the first 60 seconds of system operation. This prevents outer roll gimbal oscillation during the fast erection cycle.

After 60 seconds has elasped, the outer roll gimbal is controlled by servomechansm CX B103 (item D). Relay K408 remains deenergized. Relay K409 deenergizes. The stator of B103 is connected to the vertical gyro pitch gimbal. The rotor is connected to the vertical gyro. As the aircraft rolls, a signal is developed on the stator of B103. This signal is amplified and used to operate MG334, which positions the outer roll gimbal to the same position as the vertical gyro in roll axis. At the same time, a roll signal is sensed by the outer roll synchro (B301) and sent to the indicator. The indicator servomechanism holds the sphere stationary while the aircraft moves around it.

Exercises (A59):

1. State the purpose of the vertical gyro.

2. What determines the servomechanism that controls the outer roll gimbal?

3. For the first 60 seconds of operation, what happens between the roll signal of the vertical gyro and the outer roll gimbal?

A60. Describe the operation of the displacement gyro during an Immelmann turn.

Immelmann turn. Bombing operations require a continuous pitch signal throughout the Immelmann turn. In any aircraft attitude the outer roll gimbal must be held in position so an accurate pitch and roll indication can be displayed on the attitude-director indicator. This is done by servomechanisms B103 until 75° of pitch angle is reached. As the pitch angle is increased beyond 75°, the inner roll gimbal becomes less sensitive to aircraft roll and more sensitive to aircraft yaw. The azimuth gimbal becomes less sensitive to yaw and more sensitive to roll. When the aircraft reaches 90° of pitch, the inner roll gimbal senses pure yaw and azimuth gimbal senses pure roll.

When the aircraft pitches up 75°, K408 energizes and remains energized until the aircraft reaches 105° of pitch. At 105° of aircraft pitch, K408 deenergizes. Throughout this maneuiver K409 remains deenergized. Consequently, at aircraft extreme pitch attitudes (between 75° and 105° of pitch) the outer roll gimbal is controlled by servomechanism B404 to provide an accurate roll output from B301. Notice in figure 3-6 that when K408 is energized, its contacts break the direct connection between servomechanism B103 and B301. Also notice that the contacts of K408 allow the signal from B103 to be applied to resolver B404. The contacts of K408 also allow the output of B404 to be applied to the roll amplifier. The output of azimuth synchro B222 (item U) is also applied to the resolver. The pitch signal controls the position of the resolver through a servomechanism (not shown). The displacement between the resolver and its secondary winding is equivalent to aircraft pitch. At extreme pitch attitudes the outer roll gimbal is held at a position so an accurate roll signal is sensed at B301.

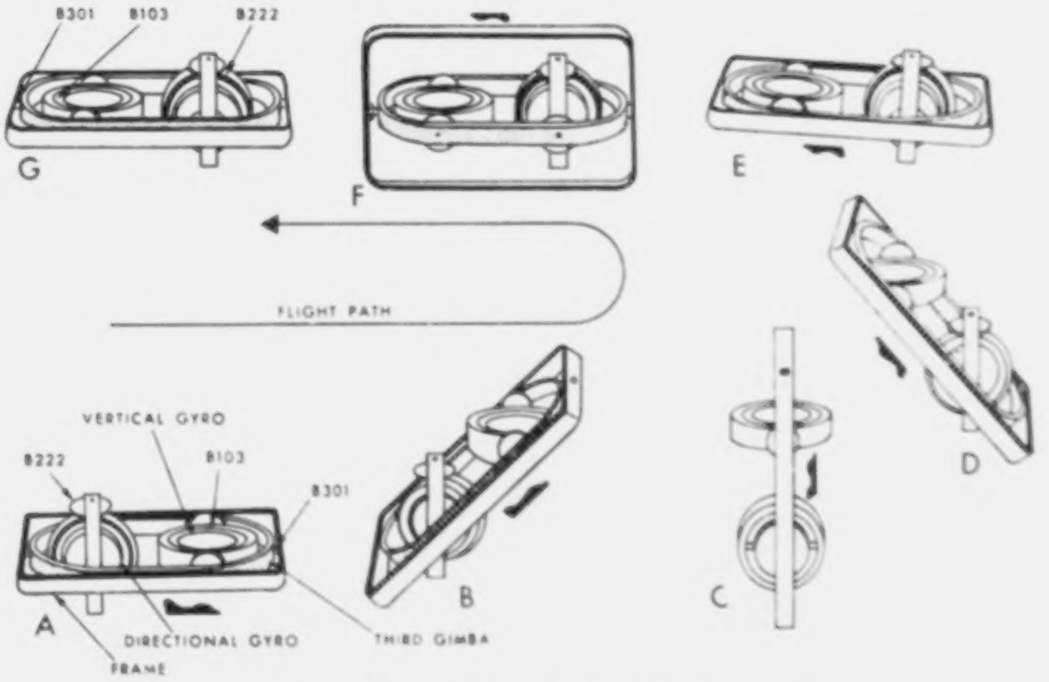


Figure 3-7A. Gimbal action during Immelman.

Remember that the Immelmann maneuver consists of a half loop and a rollout. After rollout, the rotors of all roll and azimuth synchros in the gyro package are 180° from the position they were in prior to the maneuver. The stators of these synchros also have changed by 180° except for the stator of B301. The stator of B301 did not change because it is attached to the gyro frame. Since the position of the synchros changes after the Immelmann maneuver pitch and roll phase, reversing switches are installed in the system.

These phase reversing switches control the operation of phase reversing relays. The relays energize or deenergize as the aircraft passes through 90° of pitch or roll. Phase reversal of the roll signal occurs at 90° of pitch through the phase reversing pitch relay contacts. This prevents the outer roll gimbal from driving 180° because of the reversal of the sensed signal at B103 and B222 in respect to aircraft movement. Also at 90° of pitch, the azimuth signal from CX B221 (item N) is reversed through the pitch reversing relay contacts. When the aircraft reaches 90° during rollout, roll phase reversing switch S305 (item A) energizes or deenergizes. This prevents a reverse roll signal from being applied to the CPU/4 computer. A second Immelmann returns all synchros and phase reversal switches to the original position.

Refer to figure 3-7A to better understand the Immelmann maneuver. First notice that both the vertical and directional gyros remain in a fixed position throughout the maneuver. Parts A through G of the figure illustrate how the outer roll gimbal rotates 180° around both gyros in the pitch axis. Follow the outer roll gimbal around the Immelmann turn. At position G, notice that the outer roll gimbal is inverted with respect to position A. The outer roll gimbal inverts as it passes through 90° of aircraft pitch, as illustrated in positions B, C, and D. In effect, the outer roll gimbal has flipped 180° in roll inside the gyro package frame. The rotor of the B301 has changed its position in relation to the stator by 180°. When the aircraft rolls out, the output signals of the stators are changed by 180° through a 90° roll phase reversing replay. This maintains an accurate roll signal to the CPU/4 computer. The roll signal that is applied to the CPU/4 is mixed with other signals and used as the directional steering information that is displayed on the attitude-director indicator. The phase reversing to the CPU/4 is necessary to provide the pilot with the proper steering information because the aircraft changed direction during the Immelmann turn. Next let's discuss the relation of both gyros with the outer roll gimbal.

Notice in the figure that the position of synchros B103 and B222 have changed 180° in respect to the aircraft frame during the Immelmann turn. Phase reversal switching is provided at 90° of pitch. This is done to prevent the outer roll gimbal from driving 180°. This would otherwise be caused by the reversal of the sensed signal at B103 and B222 in relation to their respective gyros.

Again, notice the position of B103 and B222 throughout the maneuver. Notice in positions A, E, F, and G that the roll signal which controls the outer roll gimbal is sensed by B103. However, at 90° it is sensed by B222. Assuming that position B represents 80° aircraft pitch and position D represents 100° of aircraft pitch, the combined signal of the two synchros control the outer roll gimbal.

To restrict the movement of the inner roll and directional gyro leveling gimbals, stops are incorporated at approximately 8°. This prevents inversion action of the gyros when power is removed during rotor coast down. Also, when power is removed, snubber friction brakes are used to restrict movement of the outer roll gimbal and the directional gyro pitch gimbal. In case of failure of the friction brakes during normal operation, servomotors have sufficient power to overcome the braking action. This completes our discussion of the gyros and their respective gimbal actions. Now, let's again go back to figure 3-6 and discuss another signal that is sensed in the gyro package, the azimuth signal.

The azimuth (heading) signal is sensed by synchro CX B221 (item N). As the aircraft yaws left or right, a signal is produced in the stator of B221. This signal is sent to the compass adapter, where is it synchronized with a magnetic slaving signal to supply an accurate heading indication. A slaving torque motor (item P) corrects for gyro drift when either a slaving or latitude correction signal is applied to this motor.

Exercises (A60):

1. After an Immelmann maneuver, how many degrees should the rotors be displaced from the stator in the roll and azimuth synchros?

2. The pitch phase reversing switch controls what units to prevent a reverse signal in the system?

3. Refer to figure 3-7. After an Immelmann turn, what is the position of the outer roll gimbal as compared to its position before the maneuver?

4. Refer to figure 3-8. How did synchros B103 and B222 change their respective positions?

5. Stops are placed in the directional gyro to limit the movement of the inner roll and leveling gimbals to approximately how many degrees?

6. Refer to figure 3-6. What is the number of the synchro in the directional gyro that senses the azimuth signal (heading)?

7. What two signals are synchronized in the compass adapter to give an accurate heading indication to the HSI?

A61. Describe the operation of components in the amplifier power supply.

Amplifier Power Supply. The amplifier power supply supplies the power for all of the system components we have just discussed. The amplifier power supply consists of three cascade amplifiers and a relay module. There are three units of the amplifier power supply; these are indicated in figure 3-8; namely, the pitch servoamplifier, the roll servoamplifier, and the directional gyro leveling amplifier. The remaining unit of the amplifier power supply is a relay module known as the starting unit. This unit contains eight relays, four bridge rectifiers, and one transformer. The eight relays are as follows:

K1: This relay becomes energized if there is a power loss of one or two phases to the vertical gyro. When K1 is energized, power is lost to the OFF flag, bringing it into view.

K2: This relay is energized during the first 12 seconds after application of power. After 12 seconds it becomes energized during aircraft turns that exceed 15° per minute. When K2 is energized, it opens the fixed phase of the vertical gyro roll torquer, thus cutting out roll erection during an aircraft turn that exceeds 15° per minute.

K3: This relay also is energized during an aircraft turn that exceeds 15° per minute. When K3 is energized, it opens the fixed phase to the vertical gyro pitch erection torquer, thus cutting out pitch erection during an aircraft turn that exceeds 15° per minute.

K4: This relay is called start relay #1. K4 is energized during the first 60 seconds after application of power.

K5: This relay is called start relay #2. K5 becomes energized 12 seconds after application of system power.

K6: This relay is called start relay #3. K6 is energized during the first 60 seconds by a set of contacts in relay #4.

K7: This is a thermal delay relay with normally closed contacts. The contacts are closed for 60 seconds. This action energizes K4.

K8: This is a thermal delay relay with normally open contacts. The contacts are opened for 12 seconds. This relay controls K5.

The bridge rectifiers convert AC to DC to operate the solenoids of relays K1 through K6. The transformer supplies the pitch and roll torque motors with erection voltage. The power transformer is not shown in this diagram. However, this power transformer supplies the necessary voltage to system components. Let's examine the operation of the starting unit to see how it maintains the proper power to the system components.

Notice in the figure that A-phase power is applied to the heating elements of K7 and K8. Also notice that

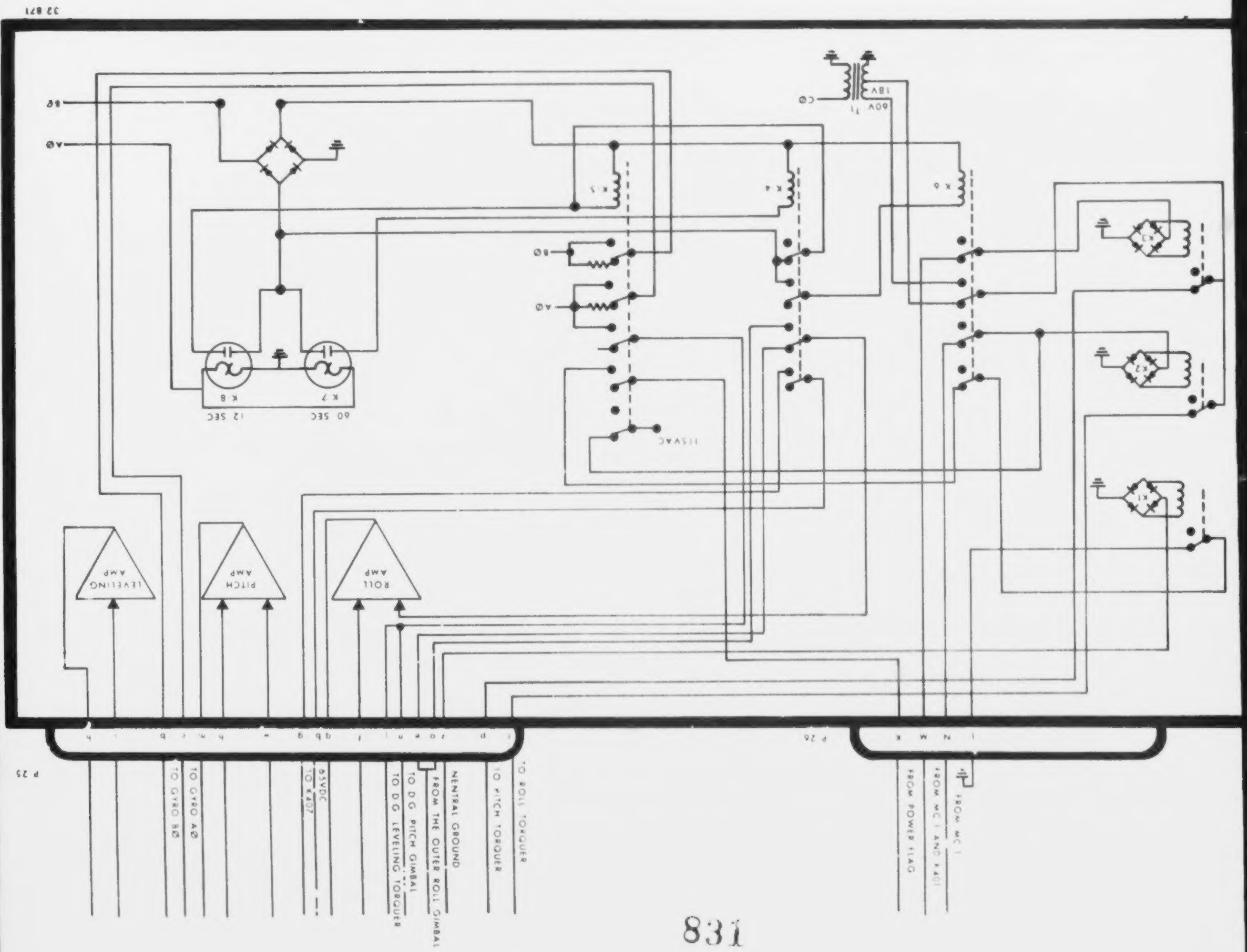

32 871
BØ
AØ
CØ
18V
60V
T1
K5
K4
K6
K3
K2
K1
BØ
AØ
K8
K7
12 SEC
60 SEC
115VAC
LEVELING AMP
PITCH AMP
ROLL AMP
P 25
P 26
TO GYRO BØ
TO GYRO AØ
65VDC TO K407
TO D.G. LEVELING TORQUER
TO D.G. PITCH GIMBAL
FROM THE OUTER ROLL GIMBAL
NEUTRAL GROUND
TO PITCH TORQUER
TO ROLL TORQUER
FROM POWER FLAG
FROM MC 1 AND K401
FROM MC 1

Figure 3-8. Amplifier power supply schematic.

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B-phase power is applied to a bridge rectifier which provides a path for direct current through K4. Relay K4 is energized for the first 60 seconds of system operation. The top set of contacts of K4 provides a path to energize B103 and B301 in the gyro package. The second set of contacts from the top has no purpose. The third set of contacts on K4 controls the operation of K6 and the last set of contacts completes a holding circuit of K5 after 60 seconds of system operation.

Since a set of contacts on K4 controls the operation of K6, K6 is also energized the first 60 seconds. Notice that the upper set of contacts on K6 is in the power flag circuit. The power flag circuit will be explained later in this objective. The second and forth sets of contacts at the top of K6 prevent the switching rate gyro (MC-1) from energizing K2 and K3 during the first 60 seconds of system operation. This is to insure the vertical gyro is erected in both roll and pitch before 60 seconds has elapsed. The third set of contacts provides the roll and pitch torque motors with high-erection voltage. Notice that K8 prevents K5 from energizing during the first 12 seconds of system operation. The reason for this is that the upper set of contacts on K5 provides power to energize K2. These contacts disable the roll erection circuit for the first 12 seconds. This prevents a possible gimbal lock which would motorize (rotate the gimbal of) the vertical gyro. Gimbal lock would occur because the pitch and roll torque motors would have high torque applied with little opposition. This is due to the lack of ridigity of the gyro during the starting cycle. The next set of contacts of K5 from the top is in the power flag circuit. The third set of contacts on K5 prevents pitch follow-up motor MG307 and the directional gyro leveling torque motor from being supplied with power the first 12 seconds. This prevents a possible gimbal lock of the directional gyro during the starting cycle. The fourth and fifth sets of contacts provide a soft start to both gyros. This prevents an excessive amount of oscillation in both gyros and their respective gimbals during the starting cycle.

After 12 seconds of system operation, the K8 contacts close and energize K5. When K5 energizes, the following events take place: K2 deenergizes, a portion of the power flag circuit is completed, power MG307 and directional gyro leveling torque motor is supplied; and 115-volt power is applied to both gyros' windings, A and B phases, so the gyros are up to speed at the end of 60 seconds.

When 60 seconds has elapsed, the contacts of K7 open and deenergize K4. When K4 deenergizes, the following events take place: K409 deenergizes, the roll input signal to the roll amplifier is switched from B301 to B103, K6 deenergizes, and K5 is supplied with a holding circuit in the event K8 should fail during flight. When K6 deenergizes, the following events take place: another portion of the power flag circuit is completed, MC1 (rate switching gyro) is allowed to cut out the roll erection motor (to prevent false erection of the vertical gyro during a turn, which would otherwise be caused by centrifugal force applied to the roll sensing switch), the high-erection voltage is removed and the low-erection voltage is applied to the pitch and roll erection motors, and the MC1 is allowed to cut out the pitch erection motor (to prevent false erection of the vertical gyro during a turn which would otherwises be caused by inertia affecting the pitch sensing switch). Also, this set of K6 contacts provides a path for current from the contacts of K401 to K3 to cut out the pitch erection motor when the aircraft makes an Immelmann turn.

After 60 seconds of system operation, the power flag circuit from the attitude-director indicator (pin K of P26) is completed up to the contact of K1. If 115-volt, wye input, three-phase, AC power is applied to the vertical gyro windings, K1 is deenergized. This provides a complete path to ground for the power flag circuit, and the power flag in the attitude-director indicator disappears. If any phase that is applied to the vertical gyro windings is low or open, the neutral ground is no longer at ground potential because the algebric sum of the induced voltage into the gyro windings is not equal to zero. This output is rectified and applied to K1, energizing this relay. The power flag comes into view because the ground is now open through the contacts of K1.

Exercises (A61):

1. The three amplifiers in the amplifier power supply are what type of amplifiers?

2. The relay module in the amplifier power supply is known by what other name?

3. What components are found in the relay module of figure 3-8?

4. Why is the switching rate gyro (MC-1) circuit to the vertical gyro not energized for the first 60 seconds of system operation?

5. How would a gimbal lock in the vertical gyro affect the gyro?

6. After 12 seconds of system operation, how much voltage is applied to both A and B phases of the gyro windings?

7. In a turn, how is false erection of the vertical gyro prevented?

8. The power-off flag should disappear from view in the ADI approximately how long after power is applied to the system?

9. The power-off flag circuit is completed to ground when what relay in the relay module in figure 3-8 is deenergized?

3-4. Heading Reference Systems

This part of the text deals with the remote compass system used in the all-attitude reference system. There are many types of remote compass systems, but the basic principles we will study here apply to all types. In some systems, some of the components may be combined into one unit to save space. We will start our discussion with the compass transmitter.

A62. Describe the function of the compass transmitter and its operation.

Compass Transmitter. This transmitter is also known as a magnetic azimuth detector. Most aircraft will use either a type C-2 or DT-198/AJN. Both units perform the same function.

The remote compass transmitter is the magnetic directing sensing component of the compass system. A hemispherical bowl contains the earth inductor element and signal transmitter. They are pendulously mounted so as to maintain an average position in the horizontal component of the earth's magnetic field, regardless of normal turbulence of the air or flight attitude changes of the aircraft. The weighted pendulum mechanism is liquid damped (restrained) to prevent excessive oscillation. The hemispherical bowl has a mounting flange with elongated slots. At the forward end of the mounting flange there is a calibration range marked off in degrees from $-10°$ to $+10°$. You use the calibration range when you align the transmitter to correct for index error.

The transmitter detects the earth's magnetic field and establishes an azimuth reference which can be used remotely to stabilize the aircraft in directional heading. The transmitter contains a sensing element called a flux valve. The flux valve is mounted by a universal joint consisting of yokes, plates, and pivots. The entire assembly is pendulously weighted and suspended in a sealed bowl. The bowl is filled with fluid to dampen out oscillation. Because it is mounted with a universal joint, the flux valve is not affected within its limits by the attitude of the aircraft about its roll and pitch axes. The pendulum points to the center of the earth. The pendulum keeps the flux valve parallel with the horizontal component of the earth's magnetic field.

The flux valve is composed of a laminated core that has low reluctance to the magnetic lines of force. It is shaped like a three-spoked wheel, with the rim split between the spokes. The flux valve's coils (pickup coils) are aligned along the spokes. At the hub of the flux valve, the spokes are connected together by a core which could be compared the the axle of a wheel. A coil, known as the exciter coil, is wrapped around this core. When AC is applied to this coil, it actually causes the earth's magnetic lines of force to move back and forth across the signal pickup coils.

Six terminal lugs are located under the cover plate of the transmitter. The lugs provide the connection for the leads that pass through the case from the transmitter to the compass system. Three leads are signal leads that connect the flux valve to the compass adapter. Two leads connect the exciter coil to a source of power. The remaining lead provides the connection to ground for shielding the signal leads.

The transmitter is constructed so that a polyplane compensator can be installed on top in place of the cover plate. The compensator, when used, counteracts deviation originating from magnetic (ferrous metal) aircraft parts located in the vicinity of the transmitter. The compensator consists of four permanent magnets. Their relative position in azimuth can be changed by rotating the two screws on the outside of the unit. You can set the polyplane compensator to the neutral position by aligning two sets of slots with dots located on the compensator case adjacent to each shaft slot.

Exercises (A62):

1. How do you correct the index error of the compass transmitter?

2. What is the purpose of the compass transmitter?

3. What is the purpose for the terminal lugs under the cover of the transmitter?

4. What is the purpose of the polyplane compensator?

A63. State the compass adapter adjustment points and operating principles.

Compass Adapter. The compass adapter contains three relays, three servomechanisms, and two amplifiers. Mechanical compensation for aircraft deviation is

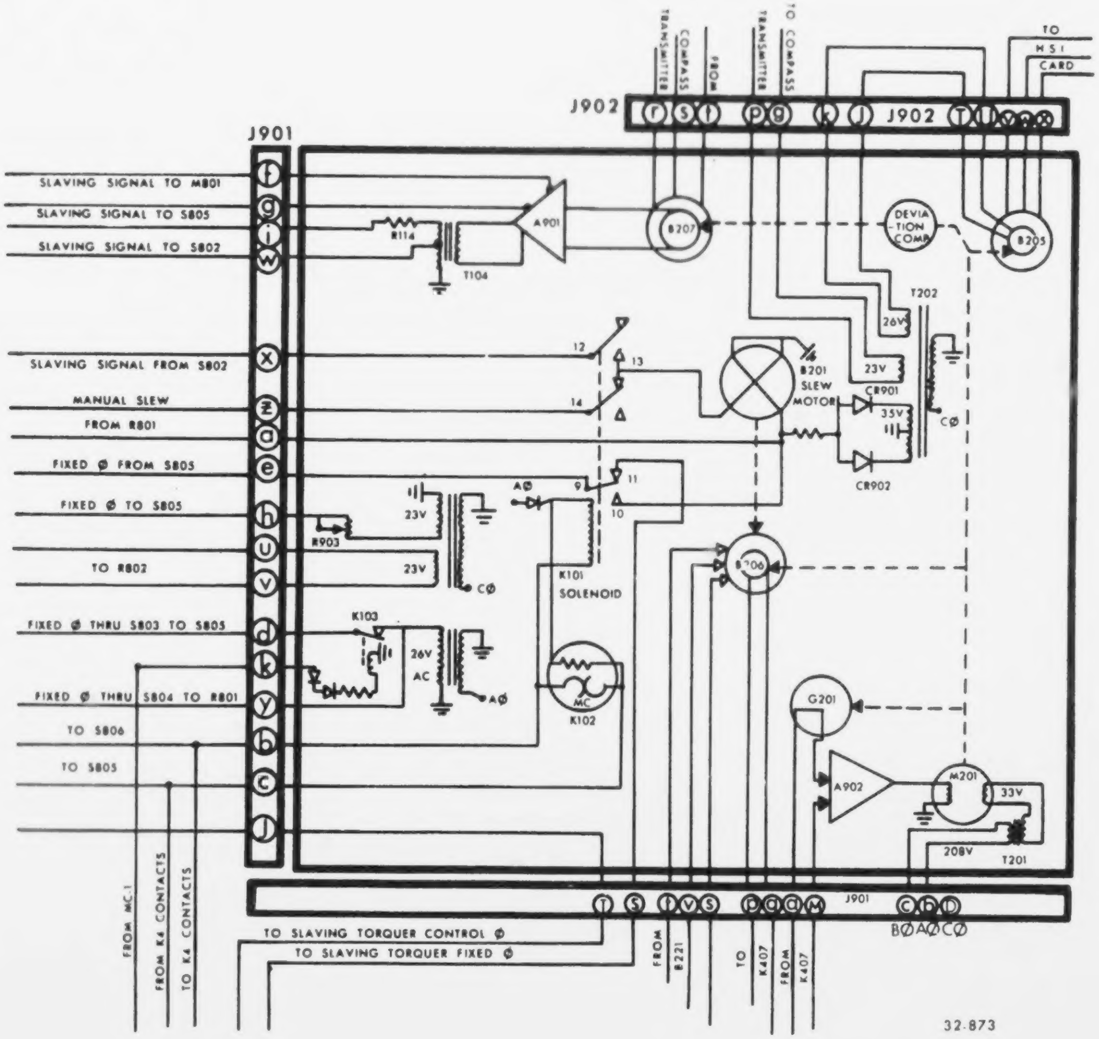
J901
J902
SLAVING SIGNAL TO M801
SLAVING SIGNAL TO S805
SLAVING SIGNAL TO S802
SLAVING SIGNAL FROM S802
MANUAL SLEW
FROM R801
FIXED Ø FROM S805
FIXED Ø TO S805
TO R802
FIXED Ø THRU S803 TO S805
FIXED Ø THRU S804 TO R801
TO S806
TO S805
FROM MC-1
FROM K4 CONTACTS
TO K4 CONTACTS
TO SLAVING TORQUER CONTROL Ø
TO SLAVING TORQUER FIXED Ø
FROM B221
TO K407
FROM K407
BØ AØ CØ
TRANSMITTER
COMPASS
FROM
TRANSMITTER
TO COMPASS
TO
H S I
CARD
R114
T104
A901
B207
DEVIA-TION COMP
B205
T202
26V
23V
B201 SLEW MOTOR
CR901
35V
CR902
CØ
12
13
14
9
11
10
AØ
23V
23V
R903
CØ
K101 SOLENOID
B206
K103
26V AC
AØ
MC
K102
G201
A902
M201
33V
208V
T201
32-873

Figure 3-9. Compass adapter schematic.

provided in this component by a cam-type compensator having 24 adjustment points. To make compensation adjustments, you remove the cover on the end opposite the connectors.

Before discussing this component, let's first get familiar with some terms that we will be using throughout our discussion. The terms for this system are:

a. Slaving signal: a signal applied to the slaving torque motor to maintain alignment of the directional gyro to the earth's magnetic field when in the slaving mode of operation.

b. Latitude correction signal: a signal applied to the slaving torque motor that turns the gyro an amount equal but opposite to apparent drift, when in the directional gyro (DG) mode of operation.

c. Synchronization: electrically nulling the azimuth signal to the slaving signal.

d. Slewing: mechanically changing the position of the stator of a synchro to cause the azimuth signal to indicate a desired heading.

Let's begin our discussion with the operation of the three relays: K101, K102, and K103. K101 is a heading synchronization relay. It controls the operation of slew motor B201 (fig. 3-9). This relay is energized only when in the slaving mode of operation because the mode selector switch (S805) in the compass controller is open in the DG mode. Anytime K101 is energized, it allows synchronization and cuts out the slaving torque motor. This relay is energized three different times by providing it with a ground. For the first 60 seconds of operation, relay K101 gets its ground through S805 by way of the contacts of K4. Another way of providing a ground for K101 is by depressing the push-to-synch switch (S806) on the compass controller. The ground circuit passes through contacts of S805. A ground is also provided for K101 when the system is switched from DG to the slave mode. This circuit passes through the contacts of K102 and then on to S805.

K102 is a 13-second time delay relay. This relay allows K101 to energize for 13 seconds when switching from DG to slave mode. When in the DG mode, the ground for the heating element of K102 is open.

K103 is a slaving cutout relay. It is energized by the switching rate gyro (MM-1) during aircraft turns. When K103 is energized, it opens the fixed phase voltage to the slaving torque motor to prevent false erection during turns.

The azimuth signal to be processed by the azimuth circuit is sensed at B221 and applied to the stator of B206 (fig. 3-9). From the rotor of B206 the azimuth signal is routed through phase reversing contacts of K407 and applied to the azimuth amplifier (A902). You should recall that K407 either energizes or deenergizes as the aircraft passes through 90° of pitch to maintain proper phasing of the signal. The output signal from A902 is applied to the control phase winding of M201. The voltage for the fixed-phase winding of M201 is supplied by transformer T201. Notice that M201 is mechanically connected to rate generator G201 and to the rotors of B205, B206, and B207. The rate generator dampens the azimuth input signal to A902. Synchro B205 is used for a heading readout of the azimuth signal on the horizontal situation indicator (HSI). The rotor of B206 is positioned by M201 to null the azimuth input signal to A902. This motor also positions the rotor of synchro B207. If the relationship between the rotor and stator of B207 is different from the relationship between the rotor and stator of B221, there is a slaving error signal induced into the rotor of B207. Let's discuss how this slaving error signal is used.

The input signal from the compass transmitter (C2) is applied to the stators of B207. The error signal from the rotor is applied to the slaving amplifier (A901). From A901 this signal is applied to the snyc indicator (M801) and to the primary winding of transformer T104. These output signals are used only in the slaving mode of system operation. The sync indicator moves to the center when the slaving and azimuth signals are synchronized. Notice that the secondary winding of T104 has two different slaving output signals. One is used by the slew· motor (B201) during synchronization. The other one is used by the slaving torque motor to correct for gyro drift while in the slaving mode of operation.

When K101 is energized, the slaving signal is routed through the contacts of switch S802 in the compass controller. From S802 the signal is routed through the closed contacts (12 and 13) of K101 and applied to B201. The slew motor is mechanically connected to the stator of B206. The slew motor positions the stator of B206 so that the output of B206 is synchronized with the output of B207. After synchronization, the slaving signal from the secondary winding of T104 is routed through voltage dropping resistor R114. From this resistor, the slaving signal is routed through S805 in the compass controller and to pin j of J901, as shown in the figure.

From pin j the slaving signal is applied to the control phase winding of the slaving torque motor. If there is any change in the earth's magnetic lines of force (such as distortion) or if the gyro drifts, this applied signal to the slaving torque motor repositions the directional gyro until B206 is at null with B207.

Notice in figure 3-9 that five transformers are shown. Transformers T201 and T104 were previously covered. T202 supplies B205 and the compass transmitter with excitation voltage. This transformer also provides a DC locking voltage for the slew motor. This prevents the slew motor from coasting and from developing an error signal in synchro B206. The transformer that has its outputs through pins h, u, and v of J901 supplies the slaving torque motor with power in the DG mode of operation through the compass controller. The output from rheostat R903 is routed through S805 and applied to the fixed-phase winding of the slaving torque motor. This adjustment compensates for random drift. The 23-volt AC through u and v is applied to the latitude compensator. This circuit will be explained in more detail when we cover the compass controller.

The transformer that has outputs through d and y of J901 supplies power to the slaving torque motor fixed-phase winding and manual slewing potentimeter R901. The 26-volt AC output through pin d is routed through the compass controller when in the slaving mode, and is applied to contact 9 of K101. When K101 is energized, this voltage is applied to the slew motor. When K101 is deenergized, this voltage is applied to the fixed-phase winding of the slaving torque motor. This voltage is removed by K103 when the aircraft is in a turn. The 26-volt AC output through pin y is routed through the compass controller, when used, and is applied to the slew motor through pins a and z of J901. This circuit also will be covered more in detail when we cover the compass controller.

Exercises (A63):

1. In the compass adapter, how many adjustment points are there on the cam-type compensator?

2. Latitude correction corrects for what and how?

3. In the slaving mode, when the sync indicator centers, what does this mean?

4. How does the slew motor aid in centering the sync indicator?

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5. In figure 3-9, why does transformer T202 supply a DC locking voltage for the slew motor?

A64. State the modes of operation of the compass controller, the basis for different selections, and the results when the slew motor operates in DG mode.

Compass Controller. The compass controller provides a means of selecting either of two modes of system operation. These modes are the slaved mode (directional gyro controlled by the slaving signal) and the DG mode (free directional gyro operation with correction for both random and apparent drift within ± 1° per hour). This component also provides a means of manually synchronizing the system to any heading. A sync indicator visually displays any misalignment between the slaving an azimuth signal.

Figure 3-10 is a schematic of the compass controller. The inputs and outputs on connector J801 are connected directly to J901 of the compass adapter. When the mode selector switch is in the slave mode, S805 contacts are in the positions shown in the figure. The top set of contacts completes a circuit for the sync indicator to center if the azimuth signal is synchronized with the slaving signal. The second set of contacts from the top completes the circuit for the slaving signal to the control phase winding of the slaving torque motor. The next set of contacts completes a circuit for the fixed phase winding of the slaving torque motor and the slew motor. The last set of contacts provides a circuit for synchronization.

When the mode selector switch is placed in the DG position, a mechanical linkage moves the contacts of S805 opposite to that shown in the figure. The top set of contacts opens the circuit to the sync indicator. The next set of contacts provides the control phase winding of the slaving torque motor with an applied voltage from the latitude compensator (R802). This is manually set to the earth's latitude to correct the directional gyro for apparent drift. Also, notice the hemisphere selector switch (S807) which is used to select the Northern or Southern Hemisphere. This simply reverses the operation of the slaving torque motor because the effects of apparent drift on the directional gyro reverse when we change the hemisphere. The next set of contacts provides the fixed-phase winding of the slaving torque motor with a voltage from R903 in the compass adapter. As you should recall, this corrects for random drift. The last set of contacts opens the ground for K101 to prevent synchronizatin.

Referring to the figure, notice that the set heading (Set Hdg) knob is a combination unit composed of

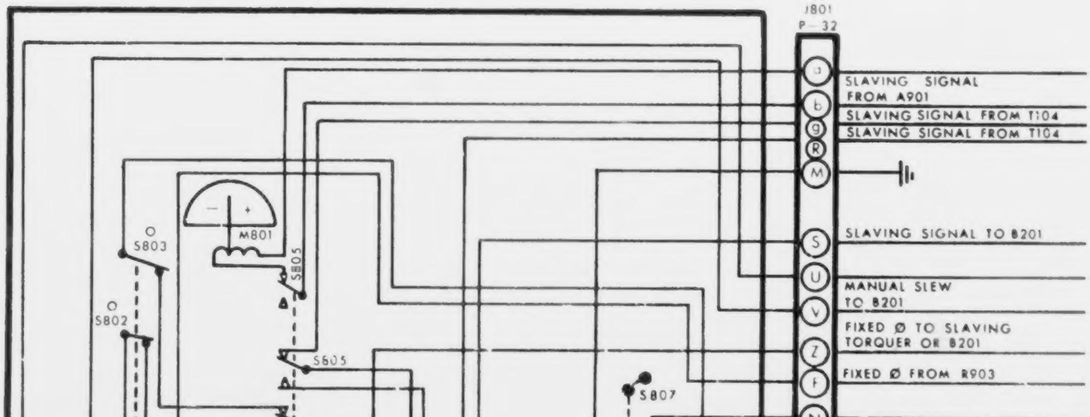

J801
P—32
a
b
g
R
M
S
U
V
Z
F
N
P
Y
T
W
X
h
L
SLAVING SIGNAL FROM A901
SLAVING SIGNAL FROM T104
SLAVING SIGNAL FROM T104
SLAVING SIGNAL TO B201
MANUAL SLEW TO B201
FIXED Ø TO SLAVING TORQUER OR B201
FIXED Ø FROM R903
23—VAC INPUT
26—VAC INPUT
26—VAC INPUT
FROM K101
FROM K102 AND K4
TO SLAVING TORQUER CONTROL Ø
M801
S803
S802
S805
S805
S805
S805
S804
S807
S806
LATITUDE COMPENSATOR
R802
R801
PUSH TO SYNC
SLAVE
DG
SET
HDG
32 874

Figure 3-10. Compass controller schematic.

microswitches and a potentiometer (R801). The set heading knob is normally in the center detent position. When depressed it opens microswitches S802 and S803 and closes S804. Contacts on S802 break the circuit of the slaving signal to the slew motor or slaving torque motor. Contacts on S804 complete a circuit for 26-volts AC to be applied to R801. The output leads of R801 are in series with the two slew motor windings. When the wiper is at center, as shown in the figure, the two currents are in phase in the motor windings. When the wiper is moved left or right from center, the resistance increases in one winding and decreases by the same amount in the other. Consequently, there is a phase shift between the two currents and the slew motor rotates. This circuit can be used to provide manual synchronization or, when in the DG mode, it can be used to move the azimuth card of the horizontal situtation indicator (HSI) to the desired heading.

Exercises (A64):

1. What are the two modes of operation of the compass controller?

2. When would the pilot make a different selectior on the hemisphere selector switch?

3. In DG mode, what happens when the slew motor operates?

A65. State where displayed heading information is read.

Horizontal Situation Indicator (HSI). Heading information is displayed on the azimuth card of the HSI in degrees of azimuth and read under a lubber line from the top of this card. Notice in figure 3-11 that the signal from B206 in the compass adapter is applied to the stator of synchro B2 in the HSI. From the stator of B2, an error signal is induced into the rotor and applied to the HSI amplifier. This output signal from the amplifier is applied to the control phase winding of MG3. The motor-generator unit drives until B2 is at null with the azimuth input signal. At the same time the card gives a visual azimuth readout and the signal is dampened by the generator. Transformer T1 supplies voltage to the fixed phase windings of the motor and generator. We will cover the HSI in more detail in the next section.

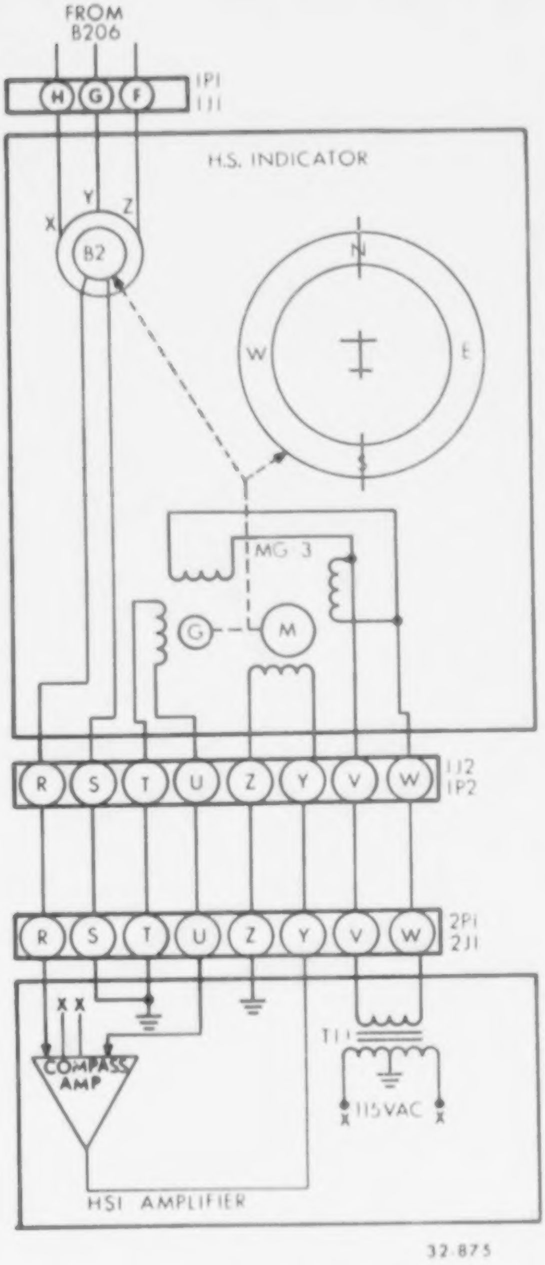


Figure 3-11. HSI azimuth schematic.

Exercises (A65):

1. The heading information displayed on the HSI azimuth card is read from what reference point?

A66. State the purpose of switching rate gyroscope and erection cutout and the moment when the switching rate gyro initiates its cutout action.

Switching Rate Gyro (SRG). The SRG provides switching during aircraft turns. It is heavily dampened to prevent actuation due to aircraft yaw oscillation. The switching action cuts out slaving, roll erection, and pitch erection during turns. This action eliminates the error caused by the compass transmitter and roll erection switch. It also allows the displacement gyro to run free in all these axes.

The roll erection and slaving cutouts are activated by the SRG during turns which exceed a rate of 15° per minute. The roll erection cutout prevents erection of the vertical gyro to a false vertical. This situation is caused by centrifugal force acting on the fluid in the roll erection switch during turns. The slaving cutout prevents the azimuth channel from slaving to an incorrect heading. This will happen when centrifugal force of turns exceeding 15° per minute acts on the pendulous flux valve.

The sensing element of the SRG is an air-damped, single-degree-of-freedom gyro. The gyro gimbal has a permanent magnet mounted on it. The magnet holds the contacts of the magnetic reed switch closed. When the aircraft turns about its yaw axis at 15° per minute or faster, the gyro precesses far enough so that the magnetic reed switch contacts open. This switch's contacts are connected in parallel with relay K-1 in the amplifier power supply. Opening of the switch allows K-1 to energize, thereby actuating the cutout circuits.

Exercises (A66):

1. What is the purpose of the SRG?

2. When does the SRG initiate this cutout action?

3. What is the prupose of roll erection cutout?

A67. Specify the operation of different components in the compass system when different modes of operation are selected.

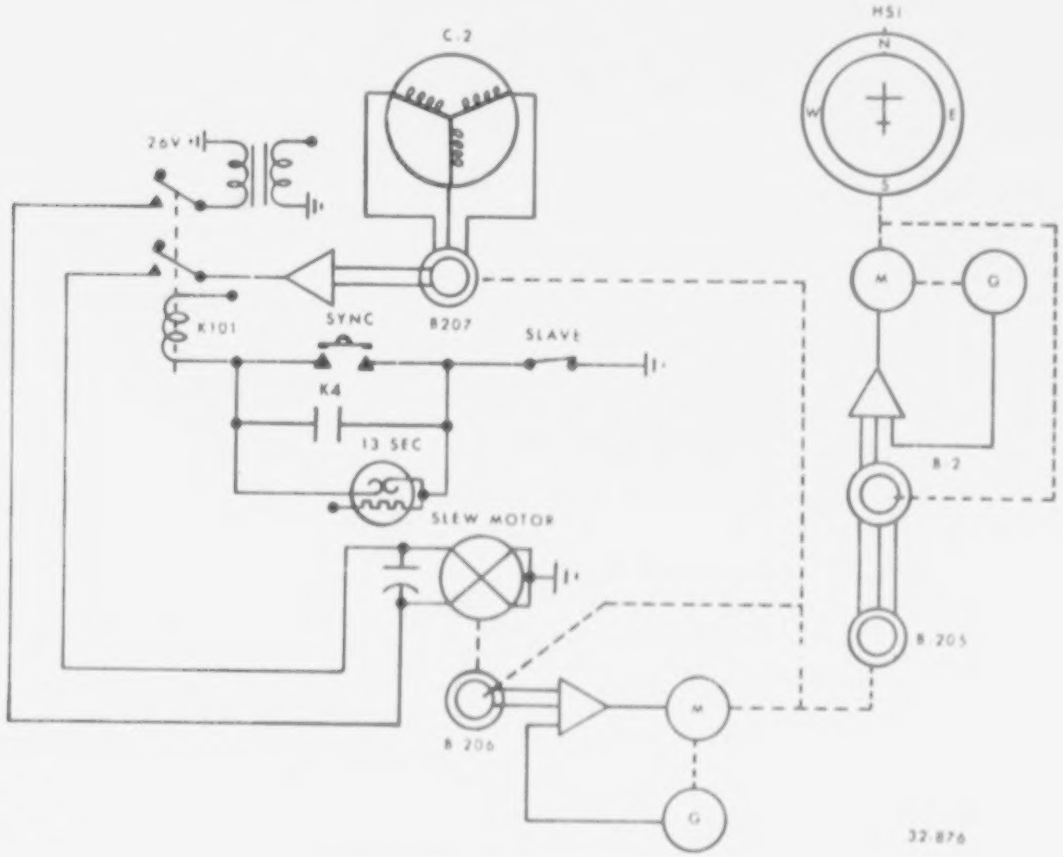


Figure 3-12. Operation during synchronization.

Now that we have covered the components of the attitude reference system, let's put them all together and discuss the tie-in of the signals. This way you will get a better understanding of overall system operation. Let us begin with the compass operation.

Compass Operation. The compass operation is broken into three different sections. These sections consist of the synchronization cycle, the slaved mode, and DG mode of operation.

Synchronization. As you should recall, synchronization occurs three different times. Each time synchronization occurs, K101 is energized. Notice the figure 3-12 that K101 is energized by the sync switch through the contacts of K4 for the first 60 seconds, and through the contacts of the thermal delay when in the slaved mode. The delay is 13 seconds when switching from DG to slaved mode. During synchronization, the signal from the azimuth synchro (B221 not shown) is applied to the stator of B206. The error signal from the rotor of B206 is amplified and applied to the azimuth motor-generator unit. Since the rotors of B205, B206, and B207 are connected to a common shaft, the HSI shows the position of these shafts in degrees on the azimuth dial. If the position of the rotor of B207 is not aligned with the signal from the C-2 transmitter, a slaving error signal develops in the rotor of B207. This error signal from B207 is applied to the slaving amplifier. The amplified signal is routed through the closed contacts of K101 and applied to the slew motor. The fixed phase is also routed through the closed contacts of K101 and applied to the slew motor. The fixed phase is also routed through a set of closed contacts of K101 and applied to the other winding of the slew motor. The slew motor is mechanically connected to the stator of B206. Since the stator of B207 is fixed and the rotors of B206 and B207 are connected to a common shaft, the slew motor drives until the stator of B206 is in the same position as the stator of B207. This simply means that B206 is nulled to B207. As the slew motor drives the stator of B206, an error signal again is developed in the rotor of B206. Consequently, B206 and B207 are electrically aligned with the azimuth synchro B221 because the gyro is a free gyro during the first 60 seconds of system operation. After the synchronization cycle the HSI indicates magnetic heading.

As you should recall from our previous discussion, gyros tend to drift. For this reason after the system is synchronized it is necessary to constantly correct the gyro for this drift to maintain a correct heading readout on the HSI.

Slaved mode. In the slaved mode of system operation, the directional gyro drift is corrected by the slaving

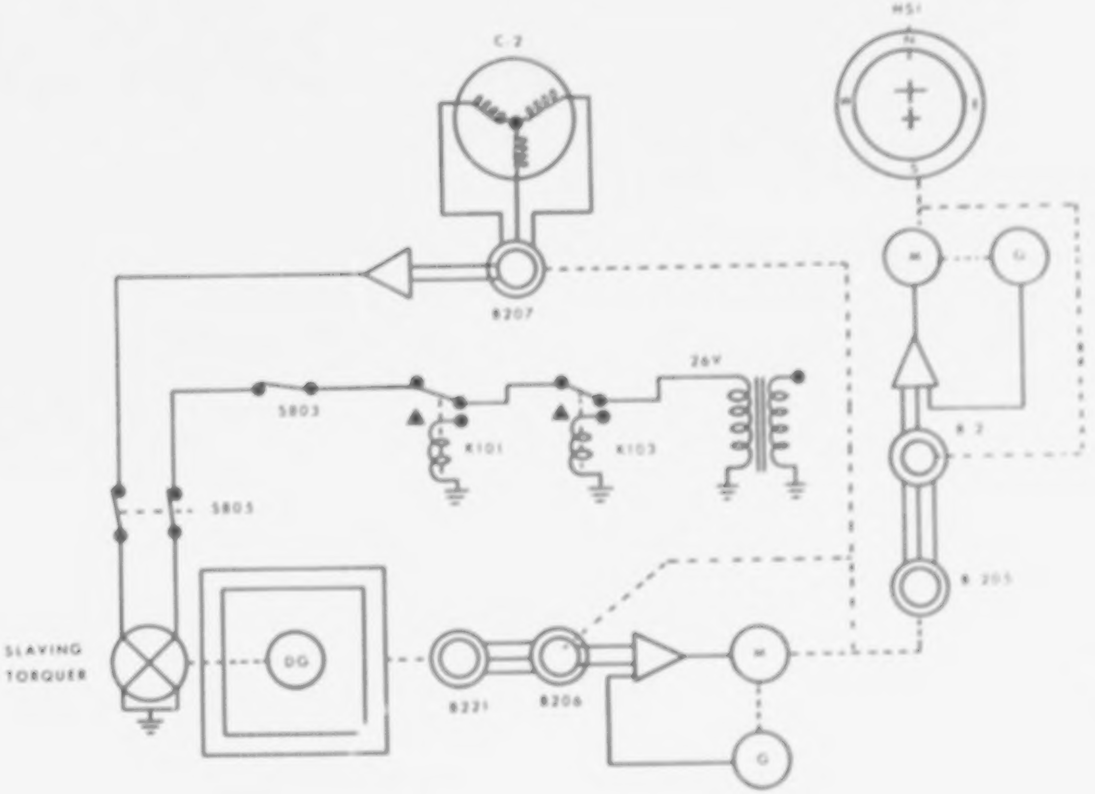


Figure 3-13. Slave mode of operation.

32 877

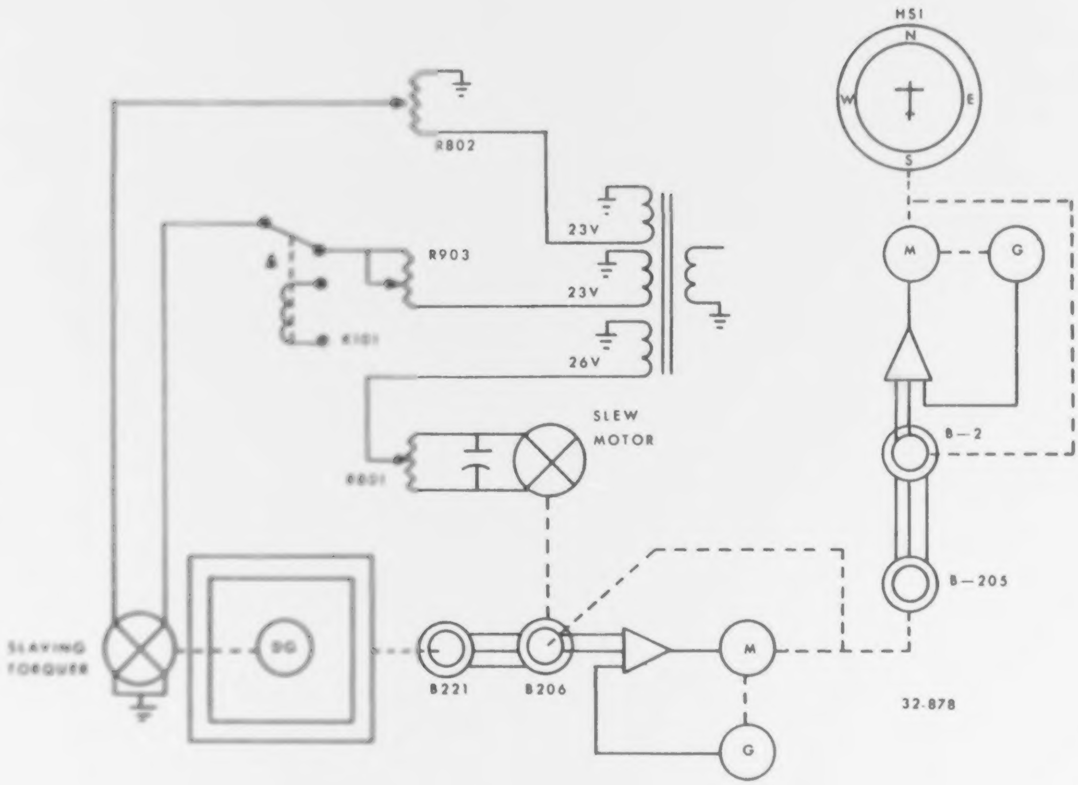


Figure 3-14. DG mode of operation.

signal. Notice in figure 3-13 that, when the gyro drifts, the rotor of B221 changes position in relation to the stator. Consequently an error is developed in the rotor of B206. This error signal is amplified and nulled at the rotor of B206 by the azimuth motor. At the same time B206 is driven to null, a slaving error signal is developed into the rotor of B207. The slaving error signal is amplified and applied to the slaving torque motor. Notice that the fixed phase voltage is applied through the contacts of K103, K101, S803, and S805 to the slaving torque motor. The slaving torque motor moves the directional gyro to its original position. A heading error signal once again is developed in the rotor of B206. Therefore, the rotors of both B206 and B207 are driven to their original position. The heading error that is caused by gyro drift is corrected before it can be detected on the HSI card.

As you should recall, there are areas throughout the world where the earth's magnetic lines of force are distorted. When the aircraft is flying in these areas the slaving signal cannot be used to maintain a true magnetic heading. For this reason, the DG mode of operation is incorporated in this system.

Directional gyro mode. In the DG mode of system operation, the directional gyro is corrected for apparent drift by the latitude compensator. This gyro is also corrected for random drift by rheostat adjustment R801. If the aircraft is flying over an area where the slaving signal is unreliable, the DG mode of operation is selected. Potentiometer R802, shown in figure 3-14, is updated to the correct latitude every 2°. If there is an error between the readout on the HSI and the actual magnetic heading, the pilot corrects the HSI by the set heading adjustment R801, illustrated in the figure. Notice in the figure that the outputs from R802 and R903 are applied to the slaving torque motor windings. The slaving torque motor applies a torque to the directional gyro to counteract total drift. Consequently, the directional gyro remains fixed in relation to the earth's surface.

Exercises (A67):

1. Every time synchronization takes place, what one relay in figure 3-12 must be energized?

2. The slew motor gets its fixed phase power from a transformer through the top contacts of what relay in figure 3-12?

840

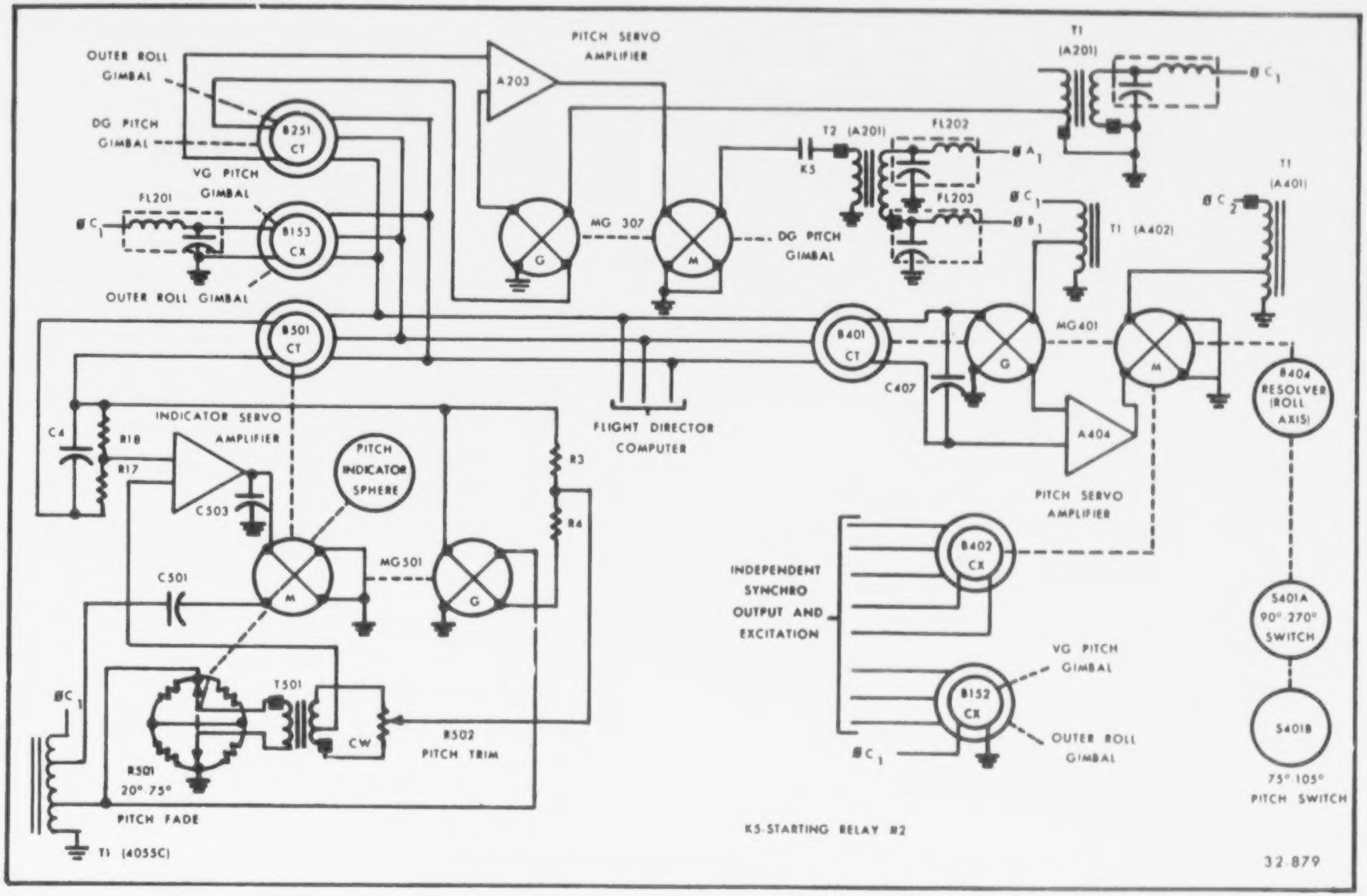

OUTER ROLL GIMBAL
DG PITCH GIMBAL
B251 CT
VG PITCH GIMBAL
FL201
ØC1
B153 CX
OUTER ROLL GIMBAL
B501 CT
PITCH SERVO AMPLIFIER
A203
MG 307
G
M
DG PITCH GIMBAL
T1 (A201)
ØC1
T2 (A201)
FL202
ØA1
K5
FL203
ØB1
ØC1
T1 (A402)
ØC2
T1 (A401)
B401 CT
C407
MG401
A404
PITCH SERVO AMPLIFIER
B404 RESOLVER (ROLL AXIS)
FLIGHT DIRECTOR COMPUTER
C4
R18
R17
INDICATOR SERVO AMPLIFIER
C503
PITCH INDICATOR SPHERE
R3
R4
MG501
C501
ØC1
T501
CW
R502 PITCH TRIM
R501 20°-75°
PITCH FADE
T1 (4055C)
INDEPENDENT SYNCHRO OUTPUT AND EXCITATION
B402 CX
VG PITCH GIMBAL
B152 CX
OUTER ROLL GIMBAL
ØC1
S401A 90°-270° SWITCH
S401B
75°-105° PITCH SWITCH
K5-STARTING RELAY #2
32-879

Figure 3-15. Pitch axis schematic.

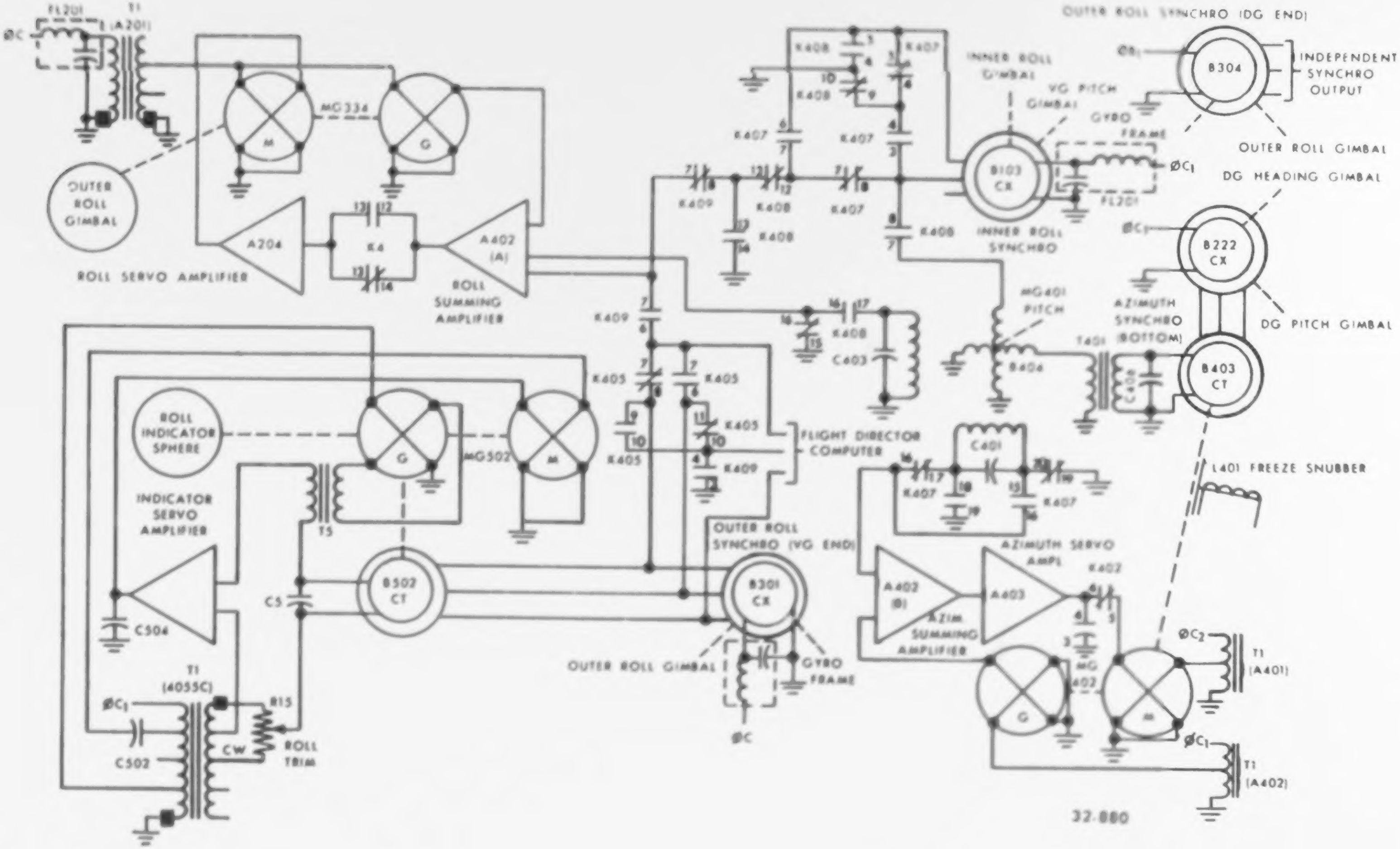

FL201
T1
(A201)
ØC
MG334
M
G
OUTER ROLL GIMBAL
A204
K4
13
12
14
A402 (A)
ROLL SERVO AMPLIFIER
ROLL SUMMING AMPLIFIER
K408
K407
K409
K405
INNER ROLL GIMBAL
VG PITCH GIMBAL
GYRO FRAME
B103 CX
INNER ROLL SYNCHRO
FL201
ØC1
OUTER ROLL SYNCHRO (DG END)
B304
INDEPENDENT SYNCHRO OUTPUT
OUTER ROLL GIMBAL
DG HEADING GIMBAL
B222 CX
DG PITCH GIMBAL
AZIMUTH SYNCHRO (BOTTOM)
T401
C404
B403 CT
MG401 PITCH
B406
C403
FLIGHT DIRECTOR COMPUTER
C401
L401 FREEZE SNUBBER
ROLL INDICATOR SPHERE
MG502
INDICATOR SERVO AMPLIFIER
T5
B502 CT
C5
C504
T1 (4055C)
ØC1
C502
CW
R15
ROLL TRIM
OUTER ROLL SYNCHRO (VG END)
B301 CX
OUTER ROLL GIMBAL
GYRO FRAME
ØC
A402 (B)
AZIM SUMMING AMPLIFIER
AZIMUTH SERVO AMPL
A403
K402
MG 402
ØC2
T1 (A401)
T1 (A402)
32-880

Figure 3-16. Roll axis schematic.

3. After the first 60 seconds of system operation and the end of the synchronization cycle, what is indicated on the azimuth dial of the HSI?

4. In the slaving mode what happens when the directional gyro drifts?

5. The DG mode of operation was incorporated in this system for what reason?

6. How is random drift adjusted for in the DG mode of operation?

A68. State operating principles of the pitch and roll channels of the attitude director system.

Attitude Operation. The attitude operation is broken into two different sections. These sections consist of the pitch and roll system operations.

Pitch operation. Notice in figure 3-15 that C-phase voltage is applied to transformers or filter networks for all control transmitters (CX) and all motor-generator units except the motor winding of MG307. This winding uses A and B phases, which are applied to T2. Also in the winding, notice the contacts of the starting relay (K5). As you should recall, K5 energizes after 12 seconds of system of operation. This prevents MG307 from operating until the directional gyro has completed its soft start cycle.

The control transmitter (CX B153), which is located between the vertical gyro pitch gimbal and outer roll gimbal in the gyro package, transmits a pitch signal to four different control transformers (CT). Each of these control transformers provides a pitch signal to a separate circuit. Each of these circuits has a different function even though their basic operations are the same.

Notice in the figure that the output signal from CX B153 is applied to CT B251, CT B401, CT B501, and the flight director computer. The function of servomechanism B251 is to keep the DG pitch gimbal perpendicular to the earth's surface. As you should recall, this circuit is located in the gyro package to provide an accurate roll signal at extreme pitch attitudes. This circuit controls the position of resolver B404 and pitch segment switches S401A and S401B. The resolver helps provide an accurate roll signal at extreme pitch attitudes. The pitch segment switch (S401A) controls the operation of the pitch phase reversing relays. Switch S401B controls the roll signal inputs and outputs to the resolver. Servomechanism B401 also controls the position of the rotor of CX B402. This synchro may be used for an independent pitch signal.

The servomechanism B501 is located in the ADI. This circuit controls the position of the sphere. The sphere presents the pictorial readout in degrees of the aircraft's pitch in relation to the earth's surface. If the operation of the pitch trim and pitch fade circuits is not obvious, refer to the explanation of these circuits earlier in this chapter. Notice that a pitch signal is also sent to the flight director computer. This circuit is explained in the next chapter. The control transmitter (CX B152) is located in the gyro package at the opposite end form CX B153. This control transmitter (CX B152) may be used for an independent pitch signal.

Roll operation. Notice in figure 3-16 that C-phase power supplies all of the motor-generator units with fixed phase voltage. The control transmitter synchros are also excited by C-phase power except for B304. This synchro is excited by B-phase power. Synchro B304 is located in the gyro package between the frame and outer roll gimbal at the opposite end from B301. Notice that B304 is an independent synchro and may be used to supply a roll signal to other systems, such as autopilot or fire control.

Remember that the output from B301 is always applied to B502. This synchro drives the sphere to indicate the relation between the rotor and stator of B301. Also, remember that the outer roll gimbal is controlled by three different signals. For the first 60 seconds, the outer gimbal is controlled by B301 through the roll phase reversing contacts (K405) and the energized contacts of K409 to the roll summing amplifier (A402). As you can see, the output from this servoloop positions the outer roll gimbal, which in turn positions the stator of B103 to null. After 60 seconds and up to 75° of aircraft pitch, the position of the outer roll gimbal is controlled by the output of B103. This output is routed through the contacts of K407, K408, and K409 to the roll summing amplifier. As the aircraft passes through 75° of pitch, the outputs from both B103 and B222 are applied to resolver B404. The signal from the resolver is routed through the contacts of K408 to the roll summing amplifier. This signal controls the position of the outer roll gimbal at extreme pitch attitudes.

Exercises (A68):

1. In the pitch circuit of figure 3-15, what phase power is applied to the rotor of controlled transmitter CXB153?

2. What is the function of servomechanism B251 in figure 3-15?

3. What does the sphere in the ADI present?

4. Referring to figure 3-16, what is the purpose of C-phase power?

5. Referring to figure 3-16, how is the outer roll gimbal controlled for the first 60 seconds of operation?

A69. State the attitude reference system inspection limitations and identify operational check reference and the rate of an error signal correction.

Maintenance. All components in this system are hermetically sealed. Therefore, the maintenance that you perform is limited to such tasks as inspection requirements, operational check, wiring repairs, component replacement, troubleshooting, and bench checking the components. In the next few objectives we cover some of these tasks.

Inspection and Operational Check. You do not disassemble the components for inspection, which is limited to external checks. You inspect the components for dents, cracks, and deformities, and check the connector for bent pins, corrosion, and stripped threads. When you perform an operational check, you must refer to the applicable TO for the specific aircraft, but there are general operating procedures for this system.

First, place the mode selector switch to the slaved mode, apply power to the system, and observe the sphere on the ADI and the compass card on the HSI. The instant after power is applied, check that the sphere moves toward the position of the aircraft in the pitch axis, provided the pitch trim knob is centered. Also at this time, check that the sphere indicates zero degrees roll and the compass card is moving toward aircraft magnetic heading. At the end of 60 seconds be sure that the gyros are erect and the power-off flag disappears. At this time the ADI displays the attitude of the aircraft and the HSI shows magnetic heading. Check the pitch trim circuit on the ADI in the same way as for the attitude indicator that was covered previously.

Next, observe the synchronous indicator on the compass controller. This indicator should be at center. Depress and then turn the set heading knob in the clockwise direction until the HSI is 30° of heading. Release the set heading knob and observe the sync indicator. This indicator should be deflected to the left, indicating a negative error. The sync indicator shows the slaving error signal. Check that this signal is corrected at a rate of 1° to 2° per minute. Determine the rate of correction by observing the change on the HSI. Next, turn the set heading knob in the counterclockwise direction until the HSI is 30° off heading in the opposite direction. The sync indicator should show a positive error signal and, again, this signal should be corrected at a rate of 1° to 2° per minute.

Next, place the mode selector switch in the DG mode of operation. Depress and turn the set heading knob both clockwise and counterclockwise and be sure that the HSI follows the movement. Remember that the sync indicator remains at center during this check. Place the latitude compensator to the correct latitude and notice the readout on the HSI. If the readout does not change more than ¼° in 15 minutes or 1° in 1 hour, the system is operating properly.

Exercises (A69):

1. Why is component inspection limited to external checks only?

2. An operational check of the system will be performed using what reference?

3. If a slaving error signal developed after 60 seconds of system operation, at approximately what rate would this error be corrected?

A70. Describe limitations in troubleshooting the attitude reference systems.

Troubleshooting and Test Equipment. You are required to troubleshoot this system if, when performing an operational check, you determine that the system does not meet the specifications as stated in the applicable TO. You are limited to making continuity and voltage checks since the components in this system are sealed. However, you may use a portable analyzer to aid you in determining which component or circuit is defective. When you perform this check always refer to the applicable TO.

The test set for checking the attitude reference system is the gyroscopic attitude control system analyzer. You use this analyzer to check all components except the switching rate gyro and the complementary components. The analyzer is furnished with a cable harness assembly, consisting of 15 test cables, and with an interconnecting box. The cable assemblies are used to connect the system components under test to the interconnecting box and the interconnecting box to the analyzer.

This analyzer consists of a metal hinged case in which the panel assembly is housed. The inside cover of the case has storage space for the cables and the interconnecting box.

This analyzer provides the necessary voltages and signals for checking the equipment under test. Meters, switches, and controls are built into the analyzer for the purpose of indicating test results, for changing select circuitry, and for making necessary voltage adjustments.

Exercises (A70):

1. What are you limited to doing when troubleshooting the attitude reference system?

2. What is the one component that the gyroscopic attitude control system analyzer will not check?

A71. Specify a piece of test equipment required for bench check and determine the rate of turn pointer indication during a bench check.

Bench Check. The bench check is performed to determine the serviceability of the system components. When performing a bench check on any of these components, you must use the applicable TO. A description of a typical bench check of one of the system components will give you an idea of the procedures involved.

When checking the rate gyroscope transmitter, for example, connect the gyro to the analyzer and mount the gyro on a turntable. Set the controls and switches of the analyzer to the positions indicated in the applicable TO. Then place the analyzer power switch to the ON position.

Adjust the turntable for a clockwise rotation of 0.75° per second and apply power to the turntable. The rate of turn pointer on the ADI should be displaced ½ division from the centerline in the direction of a right turn. Adjust the turntable rotation to 1½° per second. The rate-of-turn pointer should be displaced one division from the centerline in the direction of a right turn. Adjust the turntable rotation to 3° per second and then 6° per second respectively. The rate-of-turn pointer should now be displaced 2 divisions from the centerline with the pointer against its stop for both rates.

Repeat the procedures of the previous paragraph, but drive the turntable in the counterclockwise direction. The results should be the same except in the direction of left turn. If the gyro does not meet the tolerance given in the applicable TO for the above tests, send it to depot for overhaul.

Exercises (A71):

1. When using the analyzer to bench check a rate gyroscope transmitter, what other piece of test equipment is used?

2. With the turntable rotating at 3° per second, the rate-of-turn pointer in the ADI should be displaced from centerline how many division?

3-5. Flight Director System

You are aware that our high-performance aircraft fly higher and faster than ever. To fly a successful mission, the pilot must be furnished accurate flight information by the fastest means possible. This information must be presented in a form that can be read quickly and interpreted accurately. For this reason a new design for the flight instrument panel was developed. The indicators of the flight director system are mounted in this panel.

In this section you are given the operation of the flight director system and system components. In addition, you are given information covering the inspection, operational check, and maintenance of the system and system components as well as the test equipment used. You need this information to help you maintain the flight director system.

A72. Define related terms used with the flight director system.

Terms. The flight director system consists of two basic indicators. These indicators are the horizontal situation indicator (HSI) and the attitude director indicator (ADI). Before we can explain the operation of these indicators, we need to review some related terms. We have used 14 terms in the explanation of the system and indicators. The definitions of these terms are reviewed below.

a. VOR (VHF omnidirectional range). A radio facility which provides the pilot with course and bearing information. A VOR station provides radials which radiate from the station like spokes from the hub of a wheel. These radials are identified by their magnetic bearing from the station. For example, an aircraft can be flown magnetic north on the 0° radial from the station.

b. TACAN (tactical air navigation). A short range naviagation system much like VOR. TACAN supplies continuous accurate slant-range distance, course, and bearing information. Like VOR it provides a number of courses to or from the TACAN station from 0° to 360°. Also, through distance measuring equipment (DME) which is an integral part of TACAN, the system furnishes continuous slant-range distance from the station. This enables the crew to know the aircraft location at all times in relation to the TACAN station.

c. Data link (DA). A ground radio signal sent to the aircraft instrument system. This signal is used to display command information for the intercept mission.

d. Doppler. Radar signals which use the Doppler effect (change in a frequency when the course and the observer are in motion relative to one another) for obtaining information. The Doppler system is an automatic self-contained navigator. The system computes a solution for a navigational problem along a great circle route up to 2,000 miles. Doppler mode is selected when the aircraft is flown completely by autopilot. In this mode, on some aircraft, all steering pointers and flags are electrically pulled out of sight (biased). On other aircraft, the vertical steering pointer is used.

e. Manual. This refers to a flight during which the aircraft is being flown manually, that is, without radio or other navigational aid, other than the compass of course.

f. ILS (instrument landing system). A landing system that has three modes, ILS outbound, ILS inbound, and ILS final. Outbound is used to orient the pilot to the course of the runway when there is no GCA (ground control approach) monitoring. Inbound is used to align the aircraft with the localizer before intercepting the glidepath. Final is used when glideslope has been intercepted and the actual descent is being made.

g. Localizer. A radio beam used to help the pilot align the aircraft with the centerline of the runway.

h. Glideslope. An angular beam that gives the pilot a fixed angle of descent to the end of the runway.

i. Heading error. The difference between desired or command and actual heading.

j. Course error. The difference between the manually selected course and the actual heading of the aircraft.

k. Gain pot. A control potentiometer connected so that it can change the overall gain of an amplifier.

l. Rate pot. A potentiometer used to effect the measurements of change per unit of time in an electrical circuit.

m. Balance pot. A potentiometer used to adjust for a condition equal or near equal.

n. Limiter pot. An adjustable potentiometer that, when properly adjusted, limits the amounts of aircraft bank angle required to center the vertical steering pointer in the various flight director modes.

Exercises (A72):

1. Define "TACAN."

2. Define "data link."

3. Define "glideslope."

4. Define "course error signal."

5. Define "balance pot."

A73. Identify the channels that make up the flight director computer, and identify the mode in which both pitch and glideslope error signals are used to position the horizontal steering pointer.

Mode Selector Switch and Relays. The flight director computer operates in five basic modes: (1) manual, (2) data link (DL), (3) Doppler (auto nav), (4) TACAN, and (5) instrument landing system (ILS). The selection of a mode is made from a remote mode selector switch located on the instrument panel. The actuating of the mode select switch determines operation of relays inside the flight director computer (FDC). A simulated mode select switch, like that used to operate the relays in the FDC, is illustrated in foldout 2 located in back of volume.

The FDC consists of two channels, the roll channel and the pitch channel. The input signals to the roll channel are roll error from the vertical gyro, heading error from the HSI, and localizer receiver. Roll reference from the vertical gyro is present in all modes of operation. The use of heading error, course error or localizer signal inputs, or a combination of these signal inputs is determined by the position of the relay switches in the FDC. These relays are controlled by positioning the mode select switch to a selected flight mode. The meter driver amplifier in the roll channel amplifies the incoming signals and feeds the output signals on to the vertical steering pointer of the ADI. Input signals to the meter driver amplifier in the pitch channel are pitch errors from the vertical gyro and glideslope errors from the glideslope receiver. The pitch and glideslope error signals are used only when the mode select switch is in the ILS APPROACH position. The meter driver amplifier amplifies these input signals and sends an output signal to the horizontal steering pointer on the ADI.

Exercises (A73):

1. What two channels make up the FDC?

2. In what mode are both the pitch and glideslope error signals used to position the horizontal steering pointer?

A74. Describe flight director operation when different modes are selected.

Operation by Modes. Refer to foldout 2. It will help you understand the circuit descriptions in the text that follows. The modes to be discussed are manual, TACAN, and ILS outbound.

Manual, TACAN, and ILS outbound modes. When you place the mode selector in any of these positions, relays K1 and K4 in the FDC become energized. The bias voltage from the meter movement (M503) is removed and the vertical steering pointer is spring-actuated into view. A roll error input signal from the vertical gyro and a heading error input signal from the HSI (when such errors exist) are routed through the roll channel. They are also sent to the ADI to deflect the vertical steering pointer. This provides a fly-to indication to aid the pilot in maintaining a stable heading. MANUAL, TACAN, and ILS OUTBOUND signal positions on the mode select switch are considered heading modes. The bank limit circuit (roll limiter reference) limits the amount of bank required to center the vertical steering pointer for the selector mode. The horizontal steering pointer, localizer warning flag, and the glideslope deviation pointer are biased out of view in these modes.

Data line mode. When the mode select switch is placed in the DL position, the operation of the FDC is functionally the same as in the MANUAL, TACAN, and ILS OUTBOUND positions, except that only relay K4 is energized. This condition permits a greater allowable bank signal from the bank limit circuit to center the vertical steering pointer.

Doppler mode. The use of the vertical steering pointer on the ADI in conjunction with Doppler navigation is a feature on some aircraft and not others. When the vertical steering pointer is used, relays K1 and K4 on the FDC are energized by a remote selector switch on the instrument panel. The heading error signal from B3 in the HSI is routed through the FDC. This takes place in the same sequence as manual, TACAN, and ILS inbound modes of operation. Its purpose is to operate the vertical steering pointer.

On aircraft that do not have this capability in the Doppler mode, all pointers and flags are biased out of view. On aircraft that do have this capability, the vertical steering pointer indicates a primary steering reference to the destination.

ILS inbound mode. When the mode select switch is set in the ILS INBOUND position, relay K2 removes bias voltage and activates the vertical steering pointer. Other switches in relay K2 (K2A, K2B, and K2C) connect the course error input signal coming from the HSI and the localizer error input signal coming from the localizer receiver to the roll channel. If a roll, localizer, or course error input signal exists, the resultant signal is amplified and routed to the ADI. It deflects the vertical steering pointer and gives a fly-to indication that aids the pilot in aligning the aircraft with the center of the runway during landing. Relay K2 also connects the deviation pointer, localizer warning flag, and glideslope warning flag, in the ADI, to the localizer and glideslope radio receivers.

ILS approach mode. On foldout 2 notice that when the mode select switch is placed in the APPROACH position, relays K2 and K3 are energized. Relay K2 routes the localizer and roll error signals through the roll channel to deflect the vertical steering pointer, when such errors exist. This helps the pilot keep the aircraft on the localizer beam and maintain the proper bank during the final approach. Roll rate, localizer rate, and course rate signals are fed into the crosswind filter (amplifier filter). Switches in relay K3 provide a path for the output of the crosswind filter and disconnect the course error signal from the system. The output of the crosswind filter gives a center indication on the vertical steering pointer when the line of flight is right on the localizer radio beam. Therefore, the problem of correcting for crosswind is automatically handled by the crosswind filter in the DFC when it is operating in the ILS APPROACH mode. All the pilot needs to do is to keep the vertical steering pointer of the ADI centered, and the aircraft will fly on the localizer radio beam. Relay K3 also removes bias voltage from the meter movement (M502). The horizontal steering pointer is actuated and responds to glideslope and pitch deviations. Relay K2C removes the bias voltage and connects the glideslope pointer to the glideslope radio receiver. The glideslope pointer responds only to deviations of the glideslope signal input. Thus, it shows the displacement of the aircraft above or below the glideslope radio beam. Relay K2B also connects the localizer and glideslope warning flags with the localizer and glideslope radio receivers. The localizer and glideslope warning flags are activated (and thus held out of sight) only if the localizer and glideslope radio receivers are functioning properly. When the flags are visible, the readings of the vertical and horizontal steering pointers are not reliable.

Exercises (A74):

1. What happens to the ADI when Manual, TACAN, or ILS outbound are selected on the mode selector?

2. When Data Link mode is selected and relay K4 energizes, what does this allow for?

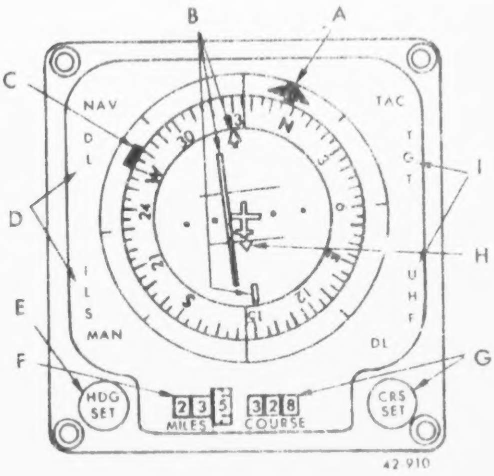
3. Refer to foldout 2. When the Doppler mode of navigation is selected, where does the heading error signal originate?

4. Refer to foldout 2. In the ILS mode of operation, if relay K2A does not energize, how would the vertical steering pointer be affected?

5. Refer to foldout 2. What relay is most likely defective if the glideslope deviation pointer remains out of view when the ILS mode is selected?

A75. Cite indications on the horizontal situation indicator.

Horizontal Situation Indicator. The horizontal situation indicator (HSI) is located in the center of the integrated instrument panel directly below the attitude director indicator. A fixed aircraft symbol, pointing upward, is located in the center of the horizontal situation indicator. A compass card rotates around the symbol, shown in figure 3-17.



A. Bearing pointer
B. Course arrow and deviation bar
C. Heading marker
D. Mode lights
E. Heading set knob
F. Distance window
G. Course arrow knob
H. To-from indicator
I. Mode lights

Figure 3-17. Horizontal situation indicator.

The aircraft heading is read under the top fixed lubber line that extends through the fixed aircraft on the indicator. The compass card is marked every 5° and labeled every 30°. The letters N, E, S, and W are used to represent 360°, 90°, 180°, and 270° respectively; moving under the aircraft symbol are a course arrow and deviation bar (B). The course arrow can be manually set by means of a knob (G) at the lower right-hand corner of the indicator. Next to the knob, and marked "COURSE SET," is a three-digit counter that has numbers ranging from 000 to 359 to provide accurate course selections.

The deviation bar rotates with the course arrow, but it is free to move and indicates the position of the aircraft in relation to the selected TACAN radial (radio beam). The TACAN radial is intercepted by turning and flying to the deviation bar.

The bearing pointer (A) on the outside of the compass shows bearing to selected stations. Or, when using the data link, it indicates relative bearing to the target.

The heading marker (C), also located on the perimeter of the compass card, it set by the knob marked"HDG SET" (E) that is on the lower left corner of the indicator. Also, it may be set automatically by heading information from the data link. The course arrow on some aircraft is servoconnected to the top of the compass card when not in use.

On the left, at the bottom of the instrument, is a window (F) through which readings from 000 to 999 show the distance to a selected station in the TACAN mode. It also shows the distance to a target in the data link mode. In addition, it shows the distance to the destination when using the Doppler mode. The number 1 in the 1000-mile-digit column on the counter comes into view when the distance is greater than 1000 miles. When distance information is not present, the distance counter is shuttered out of view. A to-from indicator in the shape of a triangle (H) is provided in the center of the instrument. It is biased out of view in ILS or when no navigational input is provided. Mode lights (D and I) illuminate around the face of the horizontal situation indicator to show the particular mode in which the instrument is being used. The symbol DL stands for data link, NAV for navigation, TAC for TACAN, TGT for target, UHF for OMNI, ILS for instrument landing system, and MAN for manual.

Six light bulbs, connected in parallel and powered by 5 volts AC or DC from the aircraft bus, light the inside of the indicator. The light bulbs are located at the top of the indicator, three on each side, and are covered by a shield. A wedge-shaped glass is located directly behind the cover glass. This arrangement gives an even distribution of light. The failure of one or two of the bulbs causes some loss of brightness. However, this has little effect on light distribution and leaves the entire indicator illuminated to a usuable degree.

Exercises (A75):

1. Where is the aircraft heading read on the HSI?

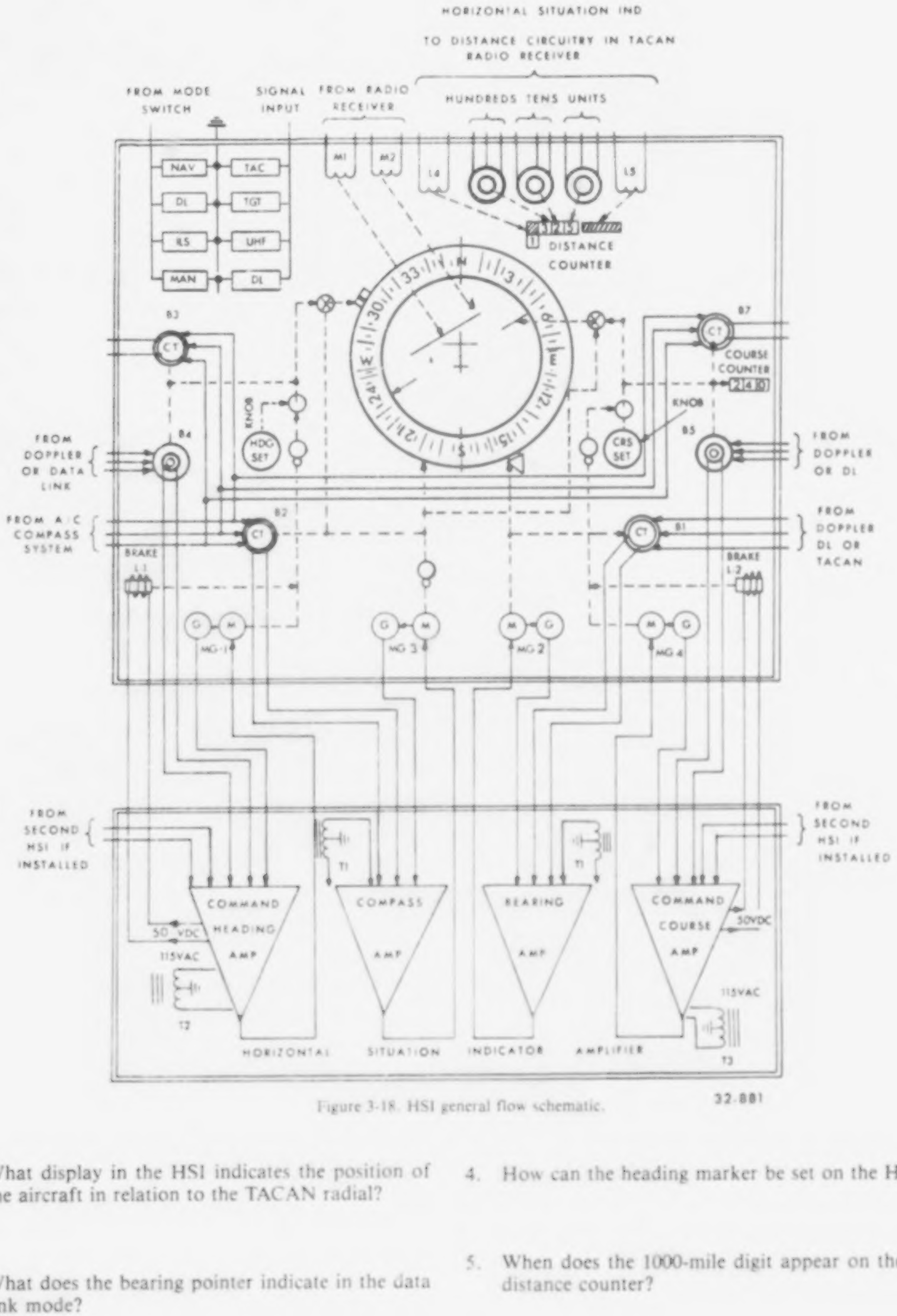

HORIZONTAL SITUATION IND
TO DISTANCE CIRCUITRY IN TACAN RADIO RECEIVER
FROM MODE SWITCH
SIGNAL INPUT
FROM RADIO RECEIVER
HUNDREDS TENS UNITS
M1
M2
L4
L5
NAV
TAC
DL
TGT
ILS
UHF
MAN
DL
DISTANCE COUNTER
B3
CT
B7
COURSE COUNTER
KNOB
KNOB
HDG SET
CRS SET
B4
B5
FROM DOPPLER OR DATA LINK
FROM DOPPLER OR DL
B2
B1
FROM A/C COMPASS SYSTEM
FROM DOPPLER DL OR TACAN
BRAKE L-1
BRAKE L-2
G
M
MG-1
MG 3
MG 2
MG 4
FROM SECOND HSI IF INSTALLED
FROM SECOND HSI IF INSTALLED
T1
T1
COMMAND HEADING AMP
COMPASS AMP
BEARING AMP
COMMAND COURSE AMP
50 VDC
50VDC
115VAC
115VAC
T2
T3
HORIZONTAL SITUATION INDICATOR AMPLIFIER

Figure 3-18. HSI general flow schematic.

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2. What display in the HSI indicates the position of the aircraft in relation to the TACAN radial?

3. What does the bearing pointer indicate in the data link mode?

4. How can the heading marker be set on the HSI?

5. When does the 1000-mile digit appear on the HSI distance counter?

A76. List the purpose of components in the HSI amplifier.

HSI Amplifier. The horizontal situation indicator (HSI) amplifier is located inside of some types of HSI indicators, but it is a separate unit with others. Regardless of this, however, the operation is the same. The HSI amplifier consists of four amplifiers and three transformers and is illustrated in figure 3-18.

The first transformer (T1) primary winding is energized in all modes by 115 volts AC from the aircraft bus. The secondary winding of this transformer supplies the necessary voltage for operating the compass and the bearing amplifier and supplies voltage to the fixed-phase windings of servomotors MG2 and MG3.

The primary winding of the third transformer (T3) is energized by 115 volts AC from the mode select switch when it is in the manual, data link, or Doppler modes of operation. The secondary winding of transformer T3 supplies the necessary voltage for the operation of the command course amplifier and the fixed-phase windings of servomotor MG4. The four amplifiers will be included in the discussions regarding the operation of the indicating sections.

Exercises (A76):

1. To which components does the secondary of (T1) supply power?

2. List the times when transformer T3 is energized.

A77. List the displays on the HSI and explain its operations.

Indicating Sections. The HSI uses the outputs from associated navigation equipment, as shown in figure 3-18, to present an integrated display of navigation data. A total of seven displays is presented on the indictor face. These displays are the compass card, bearing pointer, course arrow and counter, deviation bar, to-from arrow, heading marker, and distance counter.

Compass card. Azimuth information is displayed by a servodriven compass card, which is read against the top lubber line. Control signals from the aircraft compass system are applied to the stator windings of control transformer (CT) B2 and induce a signal in the rotor of the control transformer. This resultant signal voltage is then set to the compass amplifier, where it is amplifed and sent on to the control phase of servomotor MG3. Then servomotor MG3 drives the rotor of control transformer B2 to an electrical null position. This position is null with respect to the control transmitter (CX) located in the aircraft compass system, and positions the compass card under the top lubber line to indicate the aircraft magnetic heading or a gyro-stablized heading. When B2 is nulled, the servomoter stops and the compass card remains stationary until an error signal is again applied to the stator windings of B2.

The generator portion of MG3 is in the same unit with the servomotor, and the rotor of the generator is mounted on the same shaft as the rotor of the servomotor. When the rotor of the servomotor turns, the rotor of the generator also turns. One phase of the generator is energized by the secondary winding of T1 located in the amplifier section. The output phase (damping rate signal) is routed to the amplifier, where it damps the compass error signal coming from the rotor of control B2, thus preventing overtravel and oscillation of the compass card. Servomotor MG3 is mechanically coupled by differentials to the course arrow and heading marker. These will be discussed later in this chapter.

Bearing pointer. The bearing pointer provides pictorial bearing information to a TACAN (or VOR) station. Or, it gives the bearing to a target aircraft in the data link mode of operation. In the Doppler mode it gives bearing to destination. The information is read against the compass card. The bearing pointer is mounted on an outer perimeter ring geared to a servomotor. The bearing pointer is controlled by a servoloop in the same manner as that used to drive the compass card. The position signal for bearing pointer B1 (fig. 3-18) is received from the TACAN, Doppler, or data link receivers. The bearing amplifier amplifies the output from the transformer B1 rotor winding and then feeds it into the control phase of MG2. This motor drives the the bearing pointer to indicate the bearing to a radio facility. It positions the rotor of control transformer B1 to the electrical null with the control transmitter located in the Doppler, TACAN, or data line receiver. At null position, MG2 stops, and the bearing pointer remains stationary until a new error signal is applied to the stator windings of B1. The generator for the bearing pointer serves the same function as that previously discussed for the compass card.

Course arrow and counter. The course arrow and counter can be positioned manually or by a servomotor. The positioning knob is located on the front of the indicator at the right side. The course arrow and counter are set manually by the course-set knob (marked "COURSE SET") at the time that the mode select switch is in either the TACAN or the ILS position. In both of these modes servomotor MG4 is locked by spring-loaded solenoid brake L2. In the TACAN mode, the pilot manually sets the course arrow and counter to select the course to be flown to the TACAN station. After the course arrow has been set to the selected course, the course arrow rotates with the compass card. A differential in the servo gear train allows the compass card servomotor MG3 to drive the course arrow after it has been positioned. The differential also allows the course arrow to be set without disturbing the compass card. When the course arrow and counter are set manually or by MG4, the windings of resolver B6 (not shown) move to position the deviation bar and the to-from arrow. These indicating sections will be discussed later in this chapter.

When the mode select switch is in the ILS position, the function is the same as TACAN, except the pilot manually sets the course arrow and counter to the runway heading. B7 is connected to the system by relays contained in the flight director computer. Normally, when the mode selector switch is placed in the ILS position, the course arrow is at the lubber line. A position signal is applied to the stator windings of B7 from the aricraft compass system. When the aircraft deviates from the selected runway headings, MG3 moves the course arrow away from the lubber line. This action was previously discussed in the TACAN mode. Any time the course arrow is moved away from the lubber line, the rotor of B7 is out of null with the control transmitter in the aircraft compass system. At this time, a signal is induced into the rotor of B7 and routed to the flight director computer, thus providing a course error signal. The signal and its effect on the flight director system are discussed later in this chapter.

When the mode select switch is set at the DATA LINK position, MG4 moves the course arrow and counter to indicate the direction in which the target aircraft is flying. When the mode select switch is set at the DOPPLER position, MG4 moves the course arrow and counter to indicate ground track. The course command differential resolver B5 is used as a control transformer in these modes of operation. A position signal is routed to the stator windings of resolver B5 from the data link receiver. This signal is induced into one of the two motors in B5 and fed to the command course amplifier. Here it is amplified and routed to the control phase of MG4 at the same time L2 is energized and the brake is released, allowing MG4 to control the course arrow and counter. The servomotor turns and positions the course arrow and counter at the command indications. This, in turn, moves the stator windings of B5 to an electrical null with the control transmitter (CX) in the data link receiver. The motor then stops, and the course arrow and counter remain stationary until a new command positive signal is sent to the stator winding of B5. The rate generator in MG4 serves the same function as the one previously covered in the discussion of the compass card servoloop.

When the mode select switch is placed in the MANUAL mode of operation, an electical zero voltage from the aircraft compass system is applied to the stators of B5. Consequently, the course counter and course arrow are held by servoaction to the lubber line. This gives a digital readout of the aircraft heading at the course counter.

Deviation bar. The deviation bar is spring loaded on center and it is read against the aircraft symbol. The bar indicates the position of the aircraft, left or right of a selected course. It is positioned by the D'Asonval meter movement (M1). Resolver B6 (not shown) is positioned by the course-set knob when the mode select switch is in TACAN or ILS position. Or, it is set by command course MG4 when in DATA LINK or DOPPLER position. Position voltage is then fed to the stator of B6 from the deviation module of the TACAN or VOR receiver. Then the voltage is induced into the rotor of resolver B6 and subsequently routed back to the TACAN (or VOR) receiver through a discriminator demodulator and back to the D'Arsonval meter (M1) in the HSI. This deflects the deviation bar to make it indicate the deviation from a selected course.

To-from arrow. A meter movement (M2) controls the to-from arrow to indicate the aircraft's direction to or from a TACAN (or VOR) station. Resolver B6 controls the voltage to the meter movement (M2); the circuit is the same as that previously discussed for the deviation bar.

Heading marker. The heading marker can be positioned manually with the heading-set knob when the mode select switch is in MANUAL, TACAN, or ILS position. The heading marker allows the pilot to set in the selected compass heading as desired. After the marker is once set, it moves with the compass card. When the heading marker is at the lubber line, it indicates that the aircraft is on the selected heading. The manual heading-set mechanism is the same as the set mechanism we previously discussed when covering the course arrow. B3 serves the same function as that of B7 except that the heading error signal is routed to the flight director computer when the heading marker is moved away from the lubber line. The effect that the heading error signal has on the flight director system is discussed later in this chapter.

When the mode select switch is set at the DATA LINK or DOPPLER mode, command heading servomotor MG1 positions the marker to indicate the command heading the aircraft must fly. The operation of the command heading servoloop is the same as that previously discussed for the command course servoloop.

Distance counter. The three synchro receivers position the distance counter to drive the units, tens and hundreds dials that indicate the distance to a TACAN or Doppler station in nautical miles. The D'Arsonval meter movement (L4) positions the number 1 in view whenever the distance is greater than 1,000 miles. Another meter movement (L5) shutters the distance counters out of view whenever distance information is not available.

Exercises (A77):

1. What are the seven displays that are presented on the HSI?

2. In what two ways can the course arrow and counter be controlled?

3. When in the data link mode, why is brake L2 in the HSI energized?

4. The to-from arrow and the deviation bar are positioned by what type of meter movements?

5. When in data link or Doppler mode, if MG1 becomes inoperative what indications would be lost on the HSI?

A78. State the purpose of the jacks potentiometers on the FDC.

Flight Director Computer. The FDC is a hermetically sealed unit which accepts standard guidance and senor information which it processes for presentation as lateral and vertical steering and warning indications on the ADI. The unit is a two-channel computer which furnishes command signals by combining heading, roll, and localizer signals in the roll channel, and combining pitch and glideslope signals in the pitch channel. The computer receives input signals from the all-attitude gyro platform, the glideslope and localizer receivers, the signal-data converter, and the HSI. These input signals are phase detected, amplified, and rectified in the computer by modular, miniaturized, magnetic amplifiers, and semiconductor devices in computing circuits. The resultant output signals are applied to the ADI. The computer contains mode-switching relays, which are actuated by the mode selector switch on the instrument panel.

Twenty potentiometers are mounted on the front side of the FDC under a small cover. These 20 potentiometers are used in the alignment of the FDC. There are also 16 jacks located on the front of the FDC. These jacks and a special cable are used to make the continuity check on the FDC.

Exercises (A78):

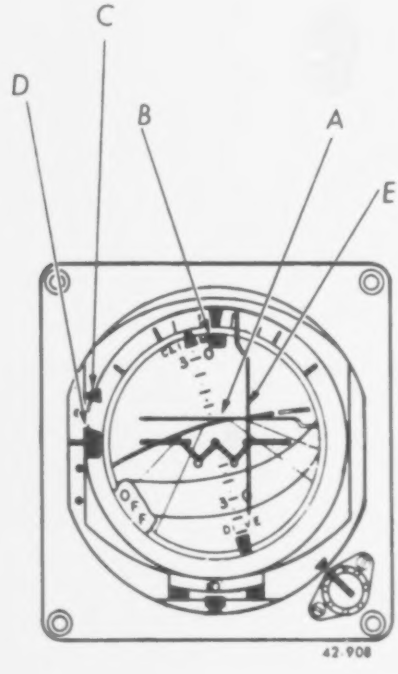
1. What is the purpose of the twenty potentiometers located on the front of the FDC?

A79. State the purpose of the localizer and glideslope warning flags and specify adjustments of the ADI.

Attitude Director Indicator (ADI). The attitude portion of the ADI was covered in a previous section. The flight director portion of the ADI is illustrated in figure 3-19. The ADI consists of the vertical and horizontal steering pointers, glideslope deviation pointer, and the warning flags. These are described in the following paragraphs. (We will explain their operation later in this chapter.)

Vertical Steering pointer. A vertical steering pointer (E) is mounted above the indicator sphere. The flight director information is displayed by a long white vertical steering pointer which moves in a horizontal plane across the face of the indicator. This pointer is out of view at the right side of the scale when it is not in use.

Horizontal steering pointer. Horizontal steering pointer (A) is mounted on the right side of the indicator. Flight director information is displayed by a long white horizontal steering pointer which moves in a vertical plane up and down the face of the indicator. This pointer is out of view at the bottom of the indicator when not in use.



A. Horizontal steering pointer
B. Localizer warning flag
C. Glidescope deviation pointer
D. Glidescope warning flag
E. Vertical steering pointer

Figure 3-19. Attitude director indicator.

Glideslope deviation pointer. Glideslope deviation pointer (C) is mounted on the left side of the indicator sphere. A vertical scale and a small moving pointer display the vertical displacement from a desired glideslope radio beam.

Localizer warning flag. The localizer warning flag (B) is mounted directly below the indicator sphere. The rectangular red flag is displayed between the inclinometer

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and the sphere. When the vertical steering pointer current fails or falls below a predetermined safe level, the localizer warning flag is activated.

Glideslope warning flag. The glideslope warning flag (D) is mounted on the left side of the indicator sphere. The rectangular red flag is displayed behind the center position of the glideslope deviation pointer. When the glideslope signal to the horizontal steering pointer or the glideslope deviation pointer fails or falls below a predetermined safe level, the glideslope flag will be activated.

Centering adjustment. On the rear of the ADI there are adjustment screws for the ADI vertical and horizontal steering pointers, glideslope deviation, and rate-of-turn pointers. You make these adjustments with POWER OFF. Two connectors are used to connect the indicator to the amplifier to the aircraft wiring.

Exercises (A79):

1. What is the purpose of the localizer and glidescope warning flags?

2. Where are the pointer centering adjustments for the ADI located?

3. When making center adjustments on the ADI, what caution must you observe?

A80. State the purpose of a diode in the FDC and properly associate malfunctions and indications in manual mode.

System Operation. The FDC receives the following input signals: (1) roll and pitch from the gyro package, (2) course and heading error from the HSI, and (3) localizer and glideslope information from the radio receivers. The output signals from the FDC are sent to the ADI. Let's discuss the output signals and how they are routed through the system in the different modes.

Manual Mode. As you read the following discussion, trace the circuits on foldout 2. When the mode selector switch is placed in the MANUAL mode of operation, as shown in foldout 2, relays K1 and K4 in the FDC are energized. The diode between K1 and K4 is a blocking diode. It keeps K1 from becoming energized when K4 is energized in the data link mode. A roll input signal from the vertical gyro is routed through transformer T4 and through resistors R7, R8, and R11 (roll gain) to the meter driver amplifier. At the meter driver amplifer, the signal is mixed with the heading error signal. The heading error signal comes from the HSI through T5 and resistors R10 and R9 (heading error). From R9 the signal is routed through the contacts of K4, which are in the energized positions, and into the demand signal amplifier limiter.

Since K1 and K4 are energized, the bias is removed from the vertical steering pointer and the pointer comes into view. K1 allows a 30° roll limit reference to be applied to the limiter in the demand signal amplifier. The 30° roll lmit reference is mixed with the heading error signal and sent to the meter driver amplifier. This mixed signal from the demand signal amplifier is applied to the meter driver amplifier and combined with the roll signal. The effective output signal from the meter driver amplifier is applied to the vertical steering pointer (M503) in the ADI through contacts of K4. The pointer provides a fly-to indication to aid the pilot in maintaining a stable heading.

Exercises (A80):

1. What is the purpose of the diode connected between relays K1 and K4 in the FDC?

2. Refer to foldout 2. What would be the indication on the vertical steering pointer if the contacts of relay K4 that are connected to pins Y and b in the roll relay assembly were stuck in the deenergized position when in the manual mode?

3. Refer to foldout 2. What would be the most probable cause if more 30° of bank was required to center the vertical steering pointer in the manual mode?

A81. Compare modes of operation and indicate the use of the 45° roll limiter.

TACAN, DOPPLER, and ILS OUTBOUND Modes. In these modes, K1 and K4, illustrated in foldout 2, are energized. The sequence of events is the same as in the manual mode.

Data Link Mode. The operation of the FDC in the data link mode is the same as the manual, TACAN, DOPPLER, and ILS OUTBOUND modes except that K4 (see FO2) is the only relay energized. A 45° roll limiter reference is applied to the demand signal amplifier. This reference permits a greater allowable bank signal to be applied to the vertical steering pointer.

Exercises (A81):

1. What mode has the same sequence of events as the TACAN, DOPPLER, and ILS OUTBOUND modes?

2. What is the 45° roll limiter used for?

A82. With an FDC wiring diagram, indicate inputs to the FDC in ILS inbound mode, the origin of course error signals, the signals applied to the vertical steering pointer, and the malfunction if an incorrect reading was noted in ILS inbound.

ILS INBOUND Mode. In the ILS INBOUND mode, K2 in the FDC, illustrated in foldout 2, energizes. Input signals to the FDC are roll, course error, and localizer signals. The output signals from the FDC are applied to the vertical steering pointer of the ADI. In this mode, the FDC also receives glideslope deviation, glideslope flag alarm, and localizer flag alarm signals. These indicating sections are covered in this section.

Vertical steering pointer. The roll signal from the gyro package is applied to T4 in the roll signal input section of the FDC. From T4, the signal is routed through R7, R8, and R11 to the meter driver amplifier. At the same time, the course error signal from the HSI is applied to T3 in the FDC. From T3 the signal is routed through R6 and R10 and through the deenergized contacts of K3 and K4. Between the contacts of K3 and K4 the localizer error signal is mixed with the course error signal. The resultant signal is applied to the demand signal amplifier through the closed contacts of K2A and K3 in the roll delay assembly. A 30° roll limit reference is applied to the limiter of the demand signal amplifier. This reference is mixed with the course error and localizer error signals from the HSI. The effective output signal is applied to the meter driver amplifier where this signal is mixed with the roll signal from the gyro package. The amplified sum of these signals is then applied to M503 in the ADI through energized relay K2A in the roll relay assembly.

The indication on the vertical steering pointer shows deviation from the roll signal, course error signal, localizer signal, and a 30° roll limiter reference. Also being applied to the FDC from the ILS receiver are the glideslope deviation, glideslope flag alarm and localized flag alarm signals.

Glideslope deviation pointer. The glideslope deviation pointer signal is applied through contacts of energized relay K2C in the FDC. This signal is applied to the glideslope deviation meter (M504) in the ADI. The pointer movement indicates deviation above or below the glideslope beam.

Glideslope warning flag. The glideslope flag alarm signal is applied through the contacts of relay K2B in the FDC. This signal is applied to the glideslope warning flag meter movement (M507) in the ADI. As long as the glideslope signal is reliable, the flag remains out of view. The flag comes into view if the glideslope signal becomes unreliable.

Localizer warning flag. The localizer flag alarm signal is applied through the contacts of relay K2B in the FDC. This signal is applied to the glideslope warning flag meter (M505) in the ADI to indicate whether or not the localizer is reliable. The glideslope warning flag comes into view if an unreliable signal is being received.

Exercises (A82):

1. Refer to foldout 2. What are the input signals to the FDC in the ILS inbound mode?

2. Refer to foldout 2. What relay would be defective if the glideslope deviation bar remained out of view in the ILS inbound mode?

3. Refer to foldout 2. Where do the course error signals originate?

4. Refer to foldout 2. What signals are applied to the vertical steering pointer in the ILS mode?

5. What indication is shown on the ADI when the glideslope signal is unreliable.

A83. Describe functions of K3 in the roll relay assembly of the FDC and state signal operation in the demand signal amplifier.

ILS Approach Mode. When the ILS approach mode is selected, K2 and K3 are energized. Notice in foldout 2 that K3 in the pitch and roll relay assembly are energized thorugh the contacts of K1 and K2A. Let's discuss the difference between the ILS approach and the ILS inbound mode of system operation.

Vertical steering pointer. Notice in foldout 2 that the roll error and localizer signals are routed in the same sequence as they were in the ILS inbound mode. Also on foldout 2, notice that in this mode the movable contact in K3 cuts out the course error signal that was mixed with the localizer error signal in the ILS inbound mode. Also notice that the same relay contact that cuts out the course error signal provides a circuit to allow the course rate, localizer rate, and roll rate signals to be mixed with the localizer error signal. These three rate signals are applied to the crosswind filter (amplifier filter) from the appropriate rate potentiometers located in the roll signal input section of the FDC. The crosswind filter prevents an error signal from being applied to the vertical steering pointer when the aircraft is flying at a crab angle. This insures that the aircraft can maintain proper course during landing. In the roll relay assembly, a contact in K3 provides a 15° roll limit reference to the demand signal amplifier. The remainder of this circuit, to the vertical steering pointer, operates the same as the ILS inbound mode.

Glideslope deviation pointer, glideslope warning flag, and localizer warning flag. The glideslope deviation pointer, glideslope warning flag, and localizer warning flag operate the same in this mode as in the ILS inbound mode. However, on foldout 2 notice that the glideslope deviation signal is applied to a modulator in the pitch signal input section of the FDC. This signal is combined with pitch signals and controls the operation of the horizontal steering pointer.

Horizontal steering pointer. From the vertical gyro (B-153) in the displacement gyro package, a pitch signal is applied to T2 in the pitch signal input section. Also, note on foldout 2 that the voltage from the approach pitch trim reference potentiometer (R16) is applied to T2. From T2, the signal is routed through the lead circuit and resistors R9, R1 (time constant adjustment), and R2 (high-pass pitch gain). At the same time a signal from T2 is routed through T4 and resistors R10 and R4 (direct pitch balance). The output of R4 is then summed with the output of R2. The glideslope deviation signal is generated in the ILS-marker beacon receiver. It is then applied to the modulator in the pitch signal input section. The glideslope signal is routed through R11 and R13 and then summed with the outputs of R2 and R4. The resultant of these three signals is applied to the demand signal amplifier at R.

At point A in the amplifier, the pitch limit signal from R14 is combined with the resultant signal. The output signal is taken from the demand signal amplifier (at point S). It is then applifed to the meter driver amplifier at R. Here it is combined with the direct pitch gain signal (Y) and the horizontal bar center input from R8 (H).

Notice in the pitch relay assembly that the movable contact in K3 removes the bias from the horizontal steering pointer. The same contact provides a circuit so that the output signal from the meter driver amplifier controls the operation of the horizontal steering pointer. In other words, this circuit moves the pointer to indicate the pitch angle the aircraft must fly to intersect the glideslope path without overshooting.

Exercises (A83):

1. Refer to foldout 2. In the ILS approach mode, what error signal is cut out by contacts K3 in the roll relay assembly?

2. What functions are provided by the closing of the contacts of relay K3 connected between pins E and C of the roll relay assembly in the FDC?

3. Refer to foldout 2. In the ILS approach mode, what is the roll limit reference in degrees that is applied to the demand signal amplifier?

4. The sum of what signals are applifed to the demand signal amplifier at R?

5. Refer to foldout 2. In the ILS approach mode, if relay K3 in the pitch relay assembly does not energize, what indication will be shown on the ADI?

A84. Describe inspection and operational check procedures for the flight director system.

Your responsibilities include two general types of maintenance of the FDC system. The first is flight line maintenance, inspection, operational check, and troubleshooting. The second is shop maintenance, which includes using the test equipment for bench check and alignment of the FDC. We discuss the first in this objective; the other in a later objective.

Flight Line Maintenance. When performing maintenance on the flight line, you are primarily concerned with the inspection of the system components, operational checks, troubleshooting, and replacement of defective parts.

Inspection. Inspection of the FDC system consists of a visual check of the FDC, the ADI, and the HSI to insure that there are no dents, cracks, or loose or missing parts. Make sure that the connector plugs are tight and secured and that there is no frayed or loose wiring going to the FDC system. If the FDC is shock mounted, check the mounts to insure that they are in good condition. If the shock mounts are in poor condition, replace them.

Operational check. The operational check for the FDC on the flight line consists of using the mode selector switch to check each mode of operation. You must check the applicable TO for the operational checks for your particular aircraft.

During an FDC system operational check, you note that certain switches are actuated, circuit breakers are set, and associated equipment is energized for the FDC to operate correctly. For this discussion, let's start with the system on and operating.

Refer to figures 3-17 and 3-19 for the following discussion. With the mode selector switch positioned to the MANUAL mode, the indications on the HSI (fig.

3-17) should indicate as shown in steps *c* through *h* below. The ADI (fig. 3-19) should indicate as shown in steps *a* and *b* below.

a. Vertical steering pointer (E) on the ADI comes into view and indicates steering deviation.

b. Horizontal steering pointer (A), glideslope deviation pointer (C), and the glideslope warning flag (D) and course warning (localizer) flags (B) are all biased out of view.

c. The azimuth dial of the HSI indicates magnetic heading of the aircraft.

d. The bearing pointer (A) is at the top lubber line of the HSI.

e. The course arrow (B) is at the top lubber line. Also, the course counter (window) (G) indicates a digital readout of magnetic heading.

f. The distance counter (window) (F) is shuttered out of view.

g. You can see the heading marker (C) can be set manually to a desired heading.

h. The mode selector light (D) reads "MAN."

The TACAN mode is the next mode to check for proper operation. With the mode selector switch on the instrument panel position to TACAN, the HSI should indicate as shown in steps *b* through *h* below. The ADI should indicate as shown in step *a* below:

a. The vertical steering pointer (E) on the ADI indicates deviations from the designated heading to the TACAN station.

b. You are able to manually set the course arrow (B) with the course set knob on the HSI to the desired TACAN radial.

c. The course deviation bar (B) indicates deviation from the selected TACAN radial.

d. The bearing pointer (A) indicates magnetic bearing to the TACAN station.

e. The distance counter (F) indicates the distance in nautical miles to the selected TACAN station.

f. The course counter (G) indicates the selected course. It agrees with the course arrow (B).

g. You are able to manually set the heading marker (C) so that it serves as a heading reference.

h. The mode light (I) on the HSI indicates "TAC."

When you turn the mode selector switch on the instrument panel to the DOPPLER mode, the HSI should indicate as shown in steps *c* through *i* below. The ADI should indicate as shown in steps *a* and *b* below.

a. The vertical steering pointer (E) on the ADI appears. Under certain conditions, it will indicate the steering correction necessary to maintain a Doppler course.

b. The course-warning flag (localizer) (B) appears if the Doppler system fails.

c. The HSI command head marker (C) indicates the heading to reach the Doppler destination.

d. The course arrow (B) indicates ground track.

e. The course deviation bar (B) aligns with the course arrow (B).

f. The bearing pointer (A) indicates the great circle course to destination.

g. The distance counter (F) indicates the nautical miles to destination.

h. The course counter (G) indicates the ground track and agrees with the course arrow (B).

i. The mode light (D) indicates "NAV."

When you place the mode selector switch on the instrument panel in the DATA LINK mode, the ADI should indicate as shown in step *a* below. The HSI should indicate as shown in steps *b* through *g* below.

a. The ADI vertical steering pointer (E) indicates deviation from a DATA LINK heading.

b. If the incoming DATA LINK signals are weak or unreliable, the course warning flag on the course window (G) appears.

c. The HSI bearing pointer (A) moves to the bearing the aircraft has to fly to reach the target.

d. The course arrow (B) moves, under certain conditions, to the target's course (direction the target aircraft is flying).

e. The heading marker (C) moves to the target intercept heading.

f. The distance counter (F) indicates the distance in slant range to the target.

g. The DL mode light (D) illuminates.

When you place the mode selector on the instrument panel to ILS OUTBOUND, the indications on the HSI and ADI will be the same as TACAN.

When you place the mode selector switch on the instrument panel to ILS INBOUND, the HSI should indicate as shown in steps *d* through *h* below. The ADI should indicate as shown in steps *a* through *c* below.

a. The ADI vertical steering pointer (E) appears. The course (localizer) (B) warning flag disappears if the signal is reliable.

b. The glideslope deviation pointer (C) disappears if the signal is reliable.

c. The horizontal steering pointer (A) is biased out of view.

d. The azimuth dial of the HSI indicates aircraft magnetic heading.

e. You are able to manually set the course arrow (B) to a localizer inbound course.

f. The course deviation bar (B) indicates a deviation left or right of the localizer course.

g. The bearing pointer (A) indicates bearing to the selected TACAN station.

h. The mode light (D) indicates ILS.

When you place the mode select on the instrument panel to the ILS APPROACH mode of operation, the HSI should indicate as shown in step *d* below. The ADI should indicate as shown in steps *a* through *c* below.

a. The vertical (E) and horizontal (A) steering pointer come into view.

b. The glideslope deviation pointer (C) comes into view at the left side of the ADI.

c. All other ADI flags are out of view if all signals are reliable.

d. The HSI indications are the same as for ILS inbound.

The indications listed above are what should happen in a typical operational check of the FDC system. If one or more of the indications do not occur as specified, you have some troubleshooting to do.

Exercises (A84):

1. Describe the inspection requirements for the flight director system.

2. When the FDC system is in the MANUAL mode, what displays are moved to the lubber line?

3. What should the heading marker in the HSI indicate when the mode selector switch is placed in the Doppler mode?

4. When the DATA LINK mode is selected, what should the course arrow indicate?

5. Referring to foldout 2, during what mode of operation is a course error signal applied to the vertical steering pointer?

6. When the mode selector switch is placed in the ILS INBOUND or the ILS APPROACH mode, what information is displayed on the deviation bar?

A85. Given some flight director system troubles and a troubleshooting chart, determine the probable cause and the remedy.

Troubleshooting. In this CDC, it is impossible for us to cover all malfunctions that could occur in the FDC system. However, the basic procedure for troubleshooting this system is the same as for other systems previously covered. Table 3-1 contains a typical checklist of troubles, with a few probable causes and remedies. As you can see from the table, most of the troubles that occur during flight line maintenance require that you replace the HSI.

Exercises (A85):

1. Determine the probable cause and remedy if the mode lights on the HSI were inoperative.

2. If, in the manual mode, the course arrow does not align with the top lubber line, what is the most probable cause?

3. Determine the probable cause and remedy if the sphere on the ADI does not follow the pitch trim knob.

A86. Identify the test equipment used to bench check and align the FDC and cable storage area, and state where bench-check procedures can be found.

Shop Maintenance. When you suspect that components are faulty, remove them from the aircraft and take them to the shop. In the shop, check the components for proper operation and repair them or send them to the depot for maintenance. Be sure to document each action.

Test equipment. The test equipment used for the bench check and alignment of the FDC is the Flight Director Computer Test Set 476E-1. This test set is shown in figure 3-20. The following list provides a brief review of the purpose of the meters, switches, receptacles, jacks, selectors, simulators, and fuses on this tester:

a. OUTPUT METER—monitors the output of the CPU-4/A.

b. LINE METER—monitors the 26-volt, 400-Hz power obtained from the power transformer fixed winding and applied to the test set, computer, and the synchro rotors.

c. EXTERNAL/INTERNAL meter switch—a switch for changing the output circuits from the output meter to the external meter jacks.

d. RATE—a switch located just below the meter switch for applying rate from the 478-2 to CPU-4/A.

e. FILTER—a switch for checking the complementary filter and the high-pass pitch circuit.

f. HEADING—a switch for changing the computer and the test set to either the manual or normal heading mode.

g. SENS SCALE—a switch for changing the output meter to a sensitive range for making null headings, checking standoff, and measuring low-level outputs.

h. POWER SWITCH—a switch for turning the test set on and off.

TABLE 3-1
FLIGHT DIRECTOR TROUBLESHOOTING

Trouble	Probable Cause	Remedy
Mode lights inoperative on HSI	Open wire between variac and indicator or bad variac	Repair or replace wiring or variac
Heading marker does not follow the heading-set knob rotation when not in Doppler or DATA LINK	Defective HSI	Replace HSI
Course arrow and course readout do not follow the course set knob rotation when not in Doppler or DATA LINK	Defective HSI	Replace HSI
In manual mode, the course arrow does not align with top lubber line	Defective HSI	Replace HSI
Course readout does not agree with compass card in manual	Defective HSI	Replace HSI
Bank steering pointer on the ADI remains stationary in ILS, localizer, and final modes	Defective HSI	Replace HSI
Sphere on ADI does not follow pitch trim knob	Defective ADI	Replace ADI

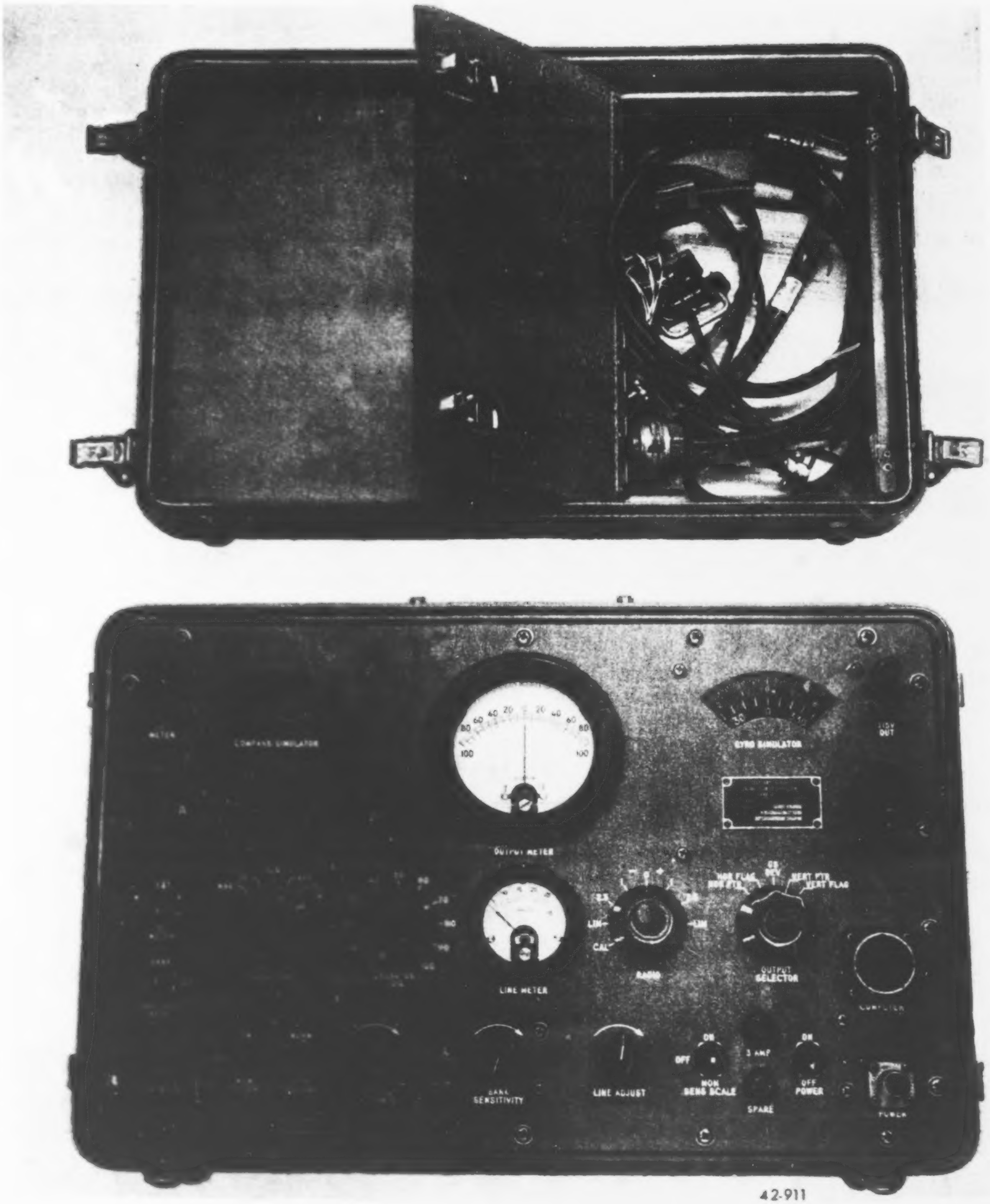
METER
COMPASS SIMULATOR
OUTPUT METER
GYRO SIMULATOR
LINE METER
RADIO
OUTPUT SELECTOR
HOR FLAG
DEV
VERT PTR
VERT FLAG
LIN
CAL
BANK SENSITIVITY
LINE ADJUST
ON
OFF
NOR
SENS SCALE
3 AMP
SPARE
POWER
42-911

Figure 3-20. Test set, FDC type 476E-1.

i. COMPUTER—a receptacle for plugging in the cable connecting the CPU-4/A to the test set.

j. POWER RECEPTACLE—for plugging in the test set power cable.

k. 478-2—a receptacle for plugging in the cable connecting the 478C-2 to the test set.

l. EXTERNAL METER JACKS—two jacks for connecting an external meter in place of test set's internal output meter.

m. 115V OUT—two jacks for monitoring the 115-volt power applied to the computer.

n. FUNCTION SELECTOR—selects the proper mode for the computer tests.

o. FLAG-GS SIG—varies the signal magnitude applied to the flag and glideslope pointer circuits.

p. RADIO—for selecting various amplitudes of radio signals. The CAL position allows accurate calibration of the radio signal.

q. OUTPUT SELECTOR—selects the proper computer output for display on the output meter.

r. BANK SENSITIVITY—varies the bank gain sensitivity in the fire control mode.

s. LINE ADJUST—adjusts voltage to the test set.

t. COMPASS SIMULATOR—a calibrated dial and synchro assembly for setting up simulated heading and course error signals. The dial and synchro are set by the knob located to the right of and below the dial.

u. GYRO SIMULATOR—a calibrated dial and synchro assembly for setting up simulated pitch and bank signals from a vertical gyro. The dial and synchro are set by the knob to the left of and below the dial.

v. FUSES—a 3-amp fuse which protects the tester. Below the main fuse holder, there is a spare fuse and holder.

Located in the lid of the test set are all necessary cables, connectors, and instructions on how to operate the tester. The applicable TO contains the instructions on how to connect these cables.

Bench check and alignment. Due to the detailed and precise bench check and alignment procedures that are outlined in the TO, it is not practical to cover these procedures in this CDC. Also, you must remember that the FDC bench check procedures are determined by the part number on the FDC. These detailed procedures are found in the applicable TO.

Exercises (A86):

1. What test equipment is used to bench check and align the FDC?

2. Where are the test cables and instruction charts for the flight director computer test set stored?

3. Where would you find the correct bench check procedures for the flight director system components installed on your assigned aircraft?

CHAPTER 4

Vertical Scale Flight Instruments

IN CHAPTER TWO of this volume, you studied the central air data computer and its outputs. In this chapter, we are going to discuss the operation and maintenance of a system that uses some CADC outputs for operation. The system consists of vertical scale flight instruments, which display flight information in the form of moving tapes. These instruments are very similar to the vertical scale engine instruments you have already studied. They display essentially the same information as the dial-type instruments, but require less space and are easier to read. To perform proper maintenance, you must have a thorough knowledge of them.

4-10. Systems Operation

In this first section, we will be discussing the system power requirements and operation of the different components in the system.

A87. Identify the components of the vertical scale flight instrument system and state the system power requirements.

Components and Power Requirements. The continual increase in speeds of high-performance, supersonic aircraft demands ever-increasing and closer vigilance by the pilot. Aircraft instrument displays must be instantly understood and flight indications immediately interpreted. The vertical scale indicators meet this demand.

Moving tapes and digital counters display the vital flight information which can be seen at a glance on the vertical scale indicators. Indicator tapes provide indications that are easily interpreted by the pilot. The vertical scale instruments eliminate the often tedious and less accurate method of reading the round dials with pointers.

The vertical scale instrument system consists of the Mach safe speed airspeed (MSSA) indicator; the MSSA amplifier; the altitude vertical-speed (AVS) indicator; and the AVS amplifier.

The signals required to position the vertical scale flight instrument tapes are provided by a CADC.

The power requirements for the vertical scale instruments are 115-volt, 400 Hz, single-phase; 5-volt, 400 Hz, single-phase; and 28-volt DC power from the aircraft power source. Also, 100-volt DC from the command data source is required for operating the command digital counters when command information from a data link ground station is being displayed.

Exercises (A87):

1. Identify the components of the vertical scale flight instrument system.

2. State the vertical scale flight instrument system power requirements.

A88. State the magnetic amplifier's power requirements and specify power and operation of the Mach safe speed auxiliary amplifier.

Operation of the Mach Safe Speed Airspeed Amplifier. The MSSA amplifier consists of a power card, an auxiliary amplifier, and seven servomagnetic amplifiers.

The power card consists of an iron core transformer with a single primary. It also has eight center-tapped secondaries.

The primary winding is supplied with 115-volt, 400 Hz, AC power. This is taken from the aircraft electrical system. The excitation voltage from the motor generator units in the MSSA indicator is supplied by the secondary windings. The required 115-volt, 400 Hz, AC voltage to the seven magnetic amplifiers is tapped off to the primary winding. Also, the 62-volt, 400 Hz, AC reference voltage is fed from the secondary winding to the magnetic amplifiers.

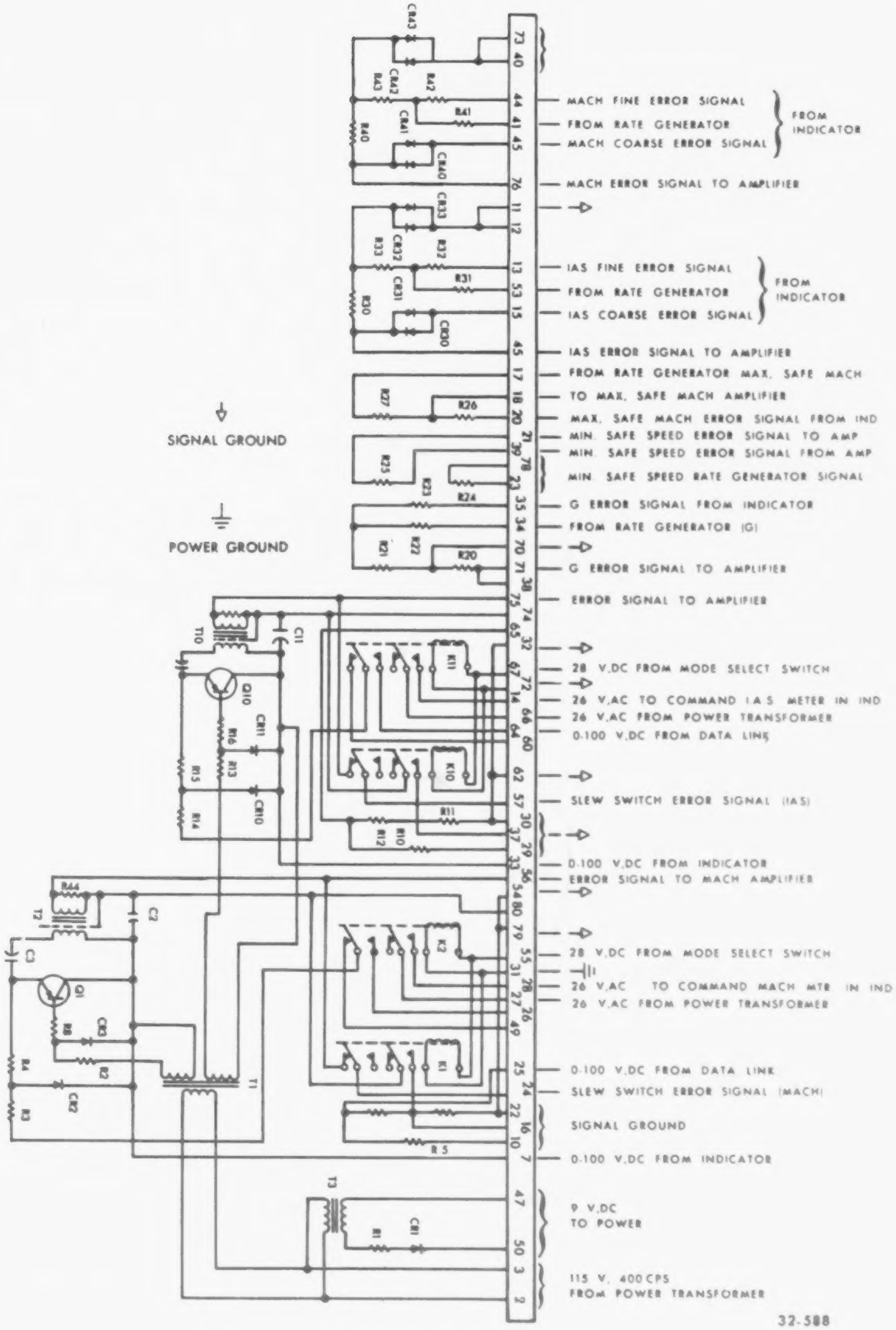
MACH FINE ERROR SIGNAL
FROM RATE GENERATOR
MACH COARSE ERROR SIGNAL
FROM INDICATOR
MACH ERROR SIGNAL TO AMPLIFIER
IAS FINE ERROR SIGNAL
FROM RATE GENERATOR
IAS COARSE ERROR SIGNAL
FROM INDICATOR
IAS ERROR SIGNAL TO AMPLIFIER
FROM RATE GENERATOR MAX. SAFE MACH
TO MAX. SAFE MACH AMPLIFIER
MAX. SAFE MACH ERROR SIGNAL FROM IND
MIN. SAFE SPEED ERROR SIGNAL TO AMP
MIN. SAFE SPEED ERROR SIGNAL FROM AMP
MIN. SAFE SPEED RATE GENERATOR SIGNAL
G ERROR SIGNAL FROM INDICATOR
FROM RATE GENERATOR (G)
G ERROR SIGNAL TO AMPLIFIER
ERROR SIGNAL TO AMPLIFIER
28 V.DC FROM MODE SELECT SWITCH
26 V.AC TO COMMAND I.A.S. METER IN IND
26 V.AC FROM POWER TRANSFORMER
0-100 V.DC FROM DATA LINK
SLEW SWITCH ERROR SIGNAL (IAS)
0-100 V.DC FROM INDICATOR
ERROR SIGNAL TO MACH AMPLIFIER
28 V.DC FROM MODE SELECT SWITCH
26 V.AC TO COMMAND MACH MTR IN IND
26 V.AC FROM POWER TRANSFORMER
0-100 V.DC FROM DATA LINK
SLEW SWITCH ERROR SIGNAL (MACH)
SIGNAL GROUND
0-100 V.DC FROM INDICATOR
9 V.DC TO POWER
115 V, 400 CPS FROM POWER TRANSFORMER
SIGNAL GROUND
POWER GROUND
CR43
CR42
R43
R42
R41
CR41
R40
CR40
CR33
CR32
R33
R32
R31
CR31
R30
CR30
R27
R26
R25
R23
R24
R21
R22
R20
T10
C11
Q10
CR11
R16
R13
R15
R14
CR10
K11
K10
R11
R12
R10
R44
T2
C2
C3
Q1
R8
CR3
R2
R4
R3
CR2
T1
K2
K1
R5
T3
R1
CR1
32-588

Figure 4-1. Auxiliary amplifier input and output signals and voltages.

The auxiliary amplifier, shown in figure 4-1, contains four relays (to control the operation of the command digital counters in the MSSA indicator) and two sets of switching diodes (to monitor the Mach and indicated airspeed signals to the magnetic amplifiers). It also contains two transistorized electronic choppers which change the data link DC input signal to a 400 Hz, AC output signal to the command magnetic amplifiers. The solenoids of relays K1, K2, K10, and K11 are energized by 28-volts DC from the flight director mode select switch. When the mode select switch is set at MANUAL, the four relays are deenergized. Then the operation of the command digital counters is controlled by slew switches on the MSSA indicator. Relays K1 and K2 control operation of the command (IAS) digital counter. When the mode select switch is in the DATA LINK position, the digital counters are controlled by signals from ground stations through data link.

There are two sets of switching diodes: one (Q1) for the Mach indicator servoloop and the other (C10) for the IAS indicator servoloop. Both of these systems employ coarse and fine signals, each derived from a synchro in the indicator. These signals are then combined in a single amplifier. For large servoerrors (signals above 300 Mv), both signals are effective in controlling the servoaction. Then as the servo approaches its null (signals below 300 Mv), and the error becomes small, the coarse signal is switched out to allow the fine signal to drive the servo to its null postion. This switching action is performed by the switching diodes. Switching diodes in the Mach indicator servosystem control fine and coarse Mach signals; those in the IAS indicator servosystem control fine and coarse IAS signals. Both circuits are identical.

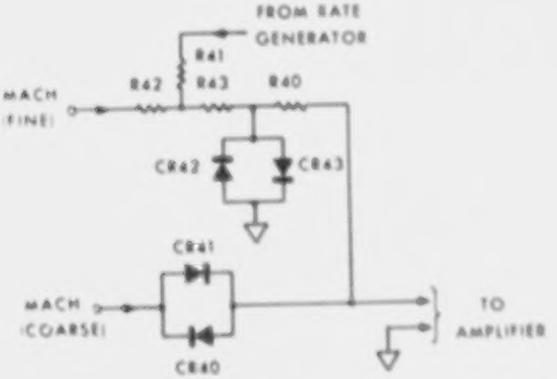

Figure 4-2. Schematic of the switching diodes and Mach servo.

The switching diode circuit contains four Zener diodes. They are in parallel pairs of two diodes each (shown in fig. 4-2). The diodes in the fine signal circuit are in parallel with the output load of the circuit. The signal voltage at the output is therefore equal to the signal voltage across CR42 and CR43 minus the small voltage drop acorss R40. This output voltage is proportional to the error signal amplitude for small error signals. For large error signals, the diodes conduct, thus limiting the large signals to values near null. In the course signal circuit, the diodes conduct for large signals and apply these signals to the amplifier. For small error signals, the diodes do not conduct. Therefore, the coarse signal is blocked. At this time, the voltage fed to the servoamplifier is the find signal voltage only. Feedback voltage to the servoamplifier input is broght from the rate generator through R41.

Two transistor chopper circuits are contained in the auxiliary amplifier. Figure 4-3 shows a schematic of one of these chopper circuits. The function of the circuits is to convert the DC signal from data link to a 400 Hz, AC signal. One of the circuits is used in the Mach indicator servosystem, and the other circuit is used in the IAS servosystem. Because both circuits operate identically, only one circuit is explained.

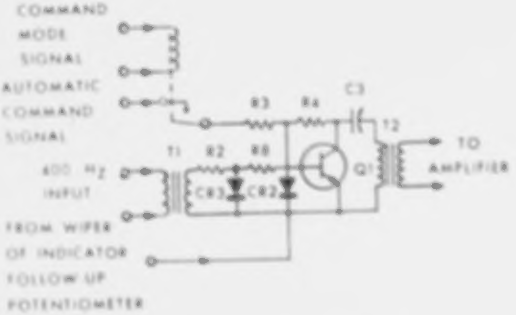

Figure 4-3. Schematic of the electronic chopper.

Notice in figure 4-3 that the 400 Hz, AC reference voltage is introduced into the circuit through transformer T1, which obtains the voltage from the Mach indicator power transformer. This voltage is reshaped to a square wave by the Zener diode CR3. Then it is applied between the base and the emitter of Q1. When the command mode signal energizes the command relay coil, the DC input signal is brought through R3 and R4 to the transistor collector. At the same time, the DC wiper voltage of the followup potentiometer in the command servosystem is fed to the transistor emitter. The collector-emitter voltage is, therefore, equal to the difference between the input signal and the potentiometer wiper signal. Thus the error signal in the command servosystem is the difference between the command signal and the potentiometer wiper signal. This error signal controls the amplification of the 400 Hz signal applied to the transistor base. Zener diode CR2 limits the amplitude of the error signal. The output of the chopper consists of the error-modulated 400 Hz signal. This signal appears at the secondary of output transformer T2 and is then fed to the servoamplifier.

The flag in the MSSA indicator indicates whether or not power is being applied to the system. It is energized by a circuit in the Mach auxiliary amplifier. This flag circuit, shown at the bottom of figure 4-1, consists of stepdown transformer T3, crystal diode CR1, and resistor R1. Figure 4-1 shows the inputs, outputs, and voltages of the auxiliary amplifier. The primary winding in the transformer is connected across the 115-volt, 400 Hz powerline. Because of the action of CR1, the alternating current through the transformer secondary is rectified. The DC component of this rectified current is brought to the flag mechanism in the MSSA indicator and it keeps the flag in its safe position. Thus, if power to the auxiliary amplifier is cut off, the current to the flag mechanism ceases to flow. The flag of the indicator shows a FAIL indication

Exercises (A88):

1. State the power requirements for operation of the magnetic amplifiers.

2. Why are four relays used in the auxiliary amplifier, and what is their voltage requirement?

3. When will the signals from both switching diodes (Q1 and Q10) be effective in controlling the servo-action?

4. How are the four switching diodes in Mach servo connected?

5. When is the feedback voltage brought from the rate generator through R41 in figure 4-2?

6. What type voltage output-wave does CR3 in figure 4-3 put out?

7. How is the flag in the MSSA indicator energized?

A89. Describe the operation of the Mach safe speed servomagnetic amplifiers.

Servomagnetic Amplifiers. There are seven two-phase induction motors in the MSSA indicator that position the vertical tapes, digital counters, and a moving marker. As a result, seven magnetic amplifiers are required in the MSSA amplifier to form seven independent closed servoloops.

The amplifier in the MSSA indicator servosystems, as well as the other servo arrangements in the equipment, is a four-stage servomagnetic amplifier, as shown in figure 4-4. This circuit consists of three RC coupled transistor voltage amplifiers. They are Q1, Q2, and Q3, and a final magnetic amplifier.

The error signal is introduced into the amplifier through the pin R of the connector. It is sent to the base of Q1 through R1 and the coupling capacitor C1. Transistor Q1 is an N-P-N type with the emitter as the common element in the circuit. The output of the first stage is taken off the collector and coupled through C3 to the base of Q2. In the second stage, essentially the same as the first, the amplified error signal is taken off the collector. The signal is then sent through C5 to the base of the third stage, Q3. In this stage, the emitter is biased by the circuit of R15, shown in figure 4-4. It is also bypassed by the paralleled capacitors C6 and C7. The arrangement is similar to the cathode biasing circuit used in a vacuum tube amplifier. Operating DC power for the first two transistors (Q1 and Q2) is obtained from full-wave power supply in which diodes CR5 and CR6 are rectifiers, and R17, R18, C11, and C12 make up the filter.

The collector voltage for Q3 is derived from the 400 Hz from pins E and K, applied alternately through the control coils of sections AM1A and AM1B and diodes CR3 and CR4 to the collector of Q3. The error signal at the base of Q3 is either in phase or 180° out of phase with the excitation at pins E and K. Thus, during the half cycle when the signal at the base of Q3 goes in the positive direction, the current increases. This is done through the particular control coil switched into conduction by the voltage at pins E and K. Conversely, the current decreases in the other control coil during the negative swing. Hence, when a voltage is applied to the base of Q3, the currents in the two control coils of the magnetic amplifier become unequal. Capacitors C8 and C9 charge and discharge through the tank circuit to provide higher output to the control windings of the motor. The phase relationship between the input error signal and the 400 Hz excitation at pins E and K determines in which control coil of the amplifier the DC current increases or decreases.

The magnitude of each DC current controls the coupling between the AC excitation applied to the primary winding of each section of the magnetic amplifier and the series connected secondary windings. If the control coil current increases toward the saturation value, the coupling is reduced, thus reducing the AC voltage induced in the secondary. Accordingly, when the DC currents become equal, the voltage induced in one secondary winding increases and decreases in the other. The windings are connected in series but are bucking, so that with no input signal to the amplifier, the 400 Hz output of the magnetic amplifier is at null. When an input signal is applied, the two secondary winding voltages become unequal. Then the net differential output

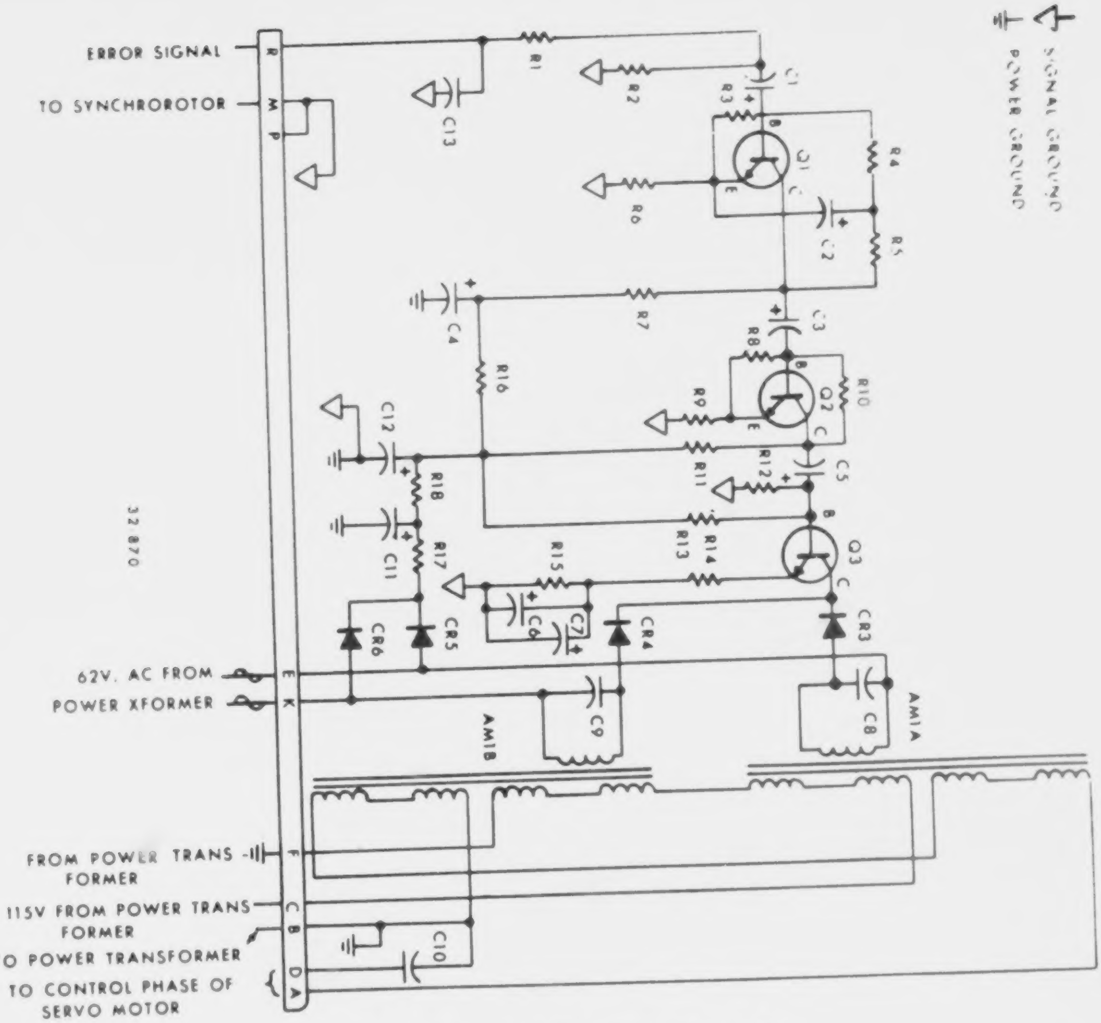
ERROR SIGNAL
TO SYNCHROROTOR
62V. AC FROM
POWER XFORMER
FROM POWER TRANS-
FORMER
115V FROM POWER TRANS-
FORMER
TO POWER TRANSFORMER
TO CONTROL PHASE OF
SERVO MOTOR
R
M
P
E
K
F
C
B
D
A
SIGNAL GROUND
POWER GROUND
R1
R2
R3
R4
R5
R6
R7
R8
R9
R10
R11
R12
R13
R14
R15
R16
R17
R18
C1
C2
C3
C4
C5
C6
C7
C8
C9
C10
C11
C12
C13
Q1
Q2
Q3
CR3
CR4
CR5
CR6
AM1A
AM1B
32 870

Figure 4-4. Schematic of the servomagnetic amplifier.

voltage is produced at pins A and B. Pins A and D are connected together. They are also connected to the output load, which is the variable phase of the servomotor. Thus capacitor C10 is across the amplifier output. It also functions as a phasing capacitor to shift the variable phase voltage 90° from the fixed-phase voltage.

Exercises (A89):

1. What is the purpose of the seven servoamplifiers incorporated in the MSSA amplifier?

2. What type amplifier circuit is used in the servomagnetic amplifier of figure 4-4?

3. What type transistor is Q1 of figure 4-4?

4. Referring to figure 4-4, what is the phase relationship between the base of Q3 and the excitation voltage at pins E and K?

5. How are the magnetic amplifiers in the MSSA amplifiers held at null when there is no input signal?

A90. Describe the Mach safe speed airspeed indicator.

Mach Safe Speed Airspeed (MSSA) Indicator. The MSSA indicator presents flight information in three sec-

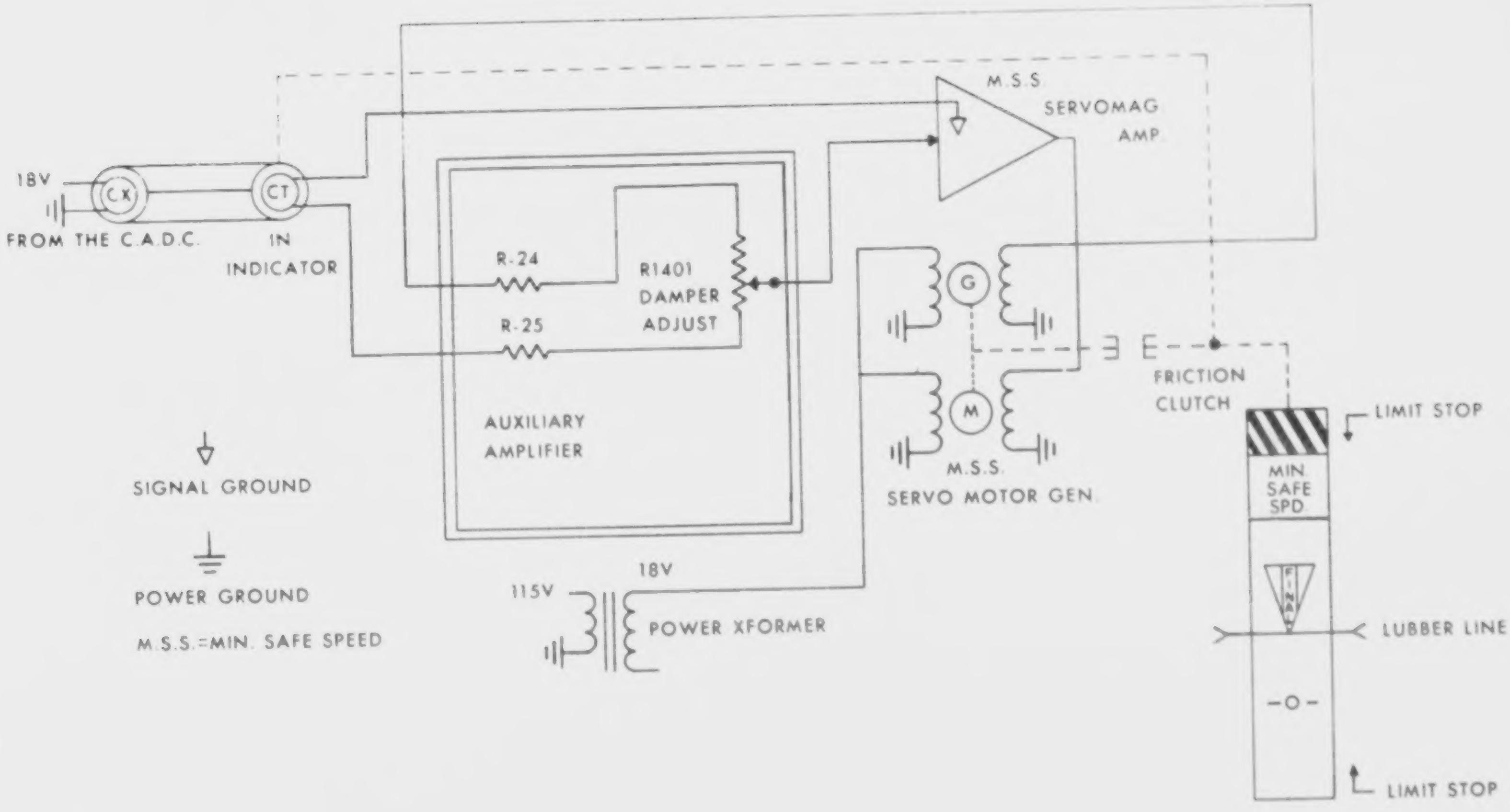
18V
C.X.
CT
FROM THE C.A.D.C.
IN
INDICATOR
M.S.S.
SERVOMAG
AMP.
R-24
R-25
R1401
DAMPER
ADJUST
AUXILIARY
AMPLIFIER
G
M
M.S.S.
SERVO MOTOR GEN.
FRICTION
CLUTCH
LIMIT STOP
MIN.
SAFE
SPD.
FINAL
LUBBER LINE
-0-
LIMIT STOP
SIGNAL GROUND
POWER GROUND
M.S.S.=MIN. SAFE SPEED
115V
18V
POWER XFORMER
42-872

Figure 4-5. Block schematic of minimum safe speed tape operation.

tions. These sections are minimum safe speed and g, Mach, and indicated airspeed. Flight information is obtained from four moving tapes. The four tape presentations are minimum safe speed (angle fo attack) g (acceleration forces), Mach (speed of the aircraft relative to the speed of sound), and IAS (indicated airspeed). These four moving tapes are read against a common horizontal reference (lubber line). The minimum safe speed and the g-tapes are side by side.

Command Mach and command airspeed are presented by markers moving over the tapes in the Mach and IAS sections. Readouts are repeated by digital counters located below these sections. Slew switches are provided on the face of the indicator to allow the pilot to set in commands during the manual modes of flight. Remote inputs from ground stations, through date link, position the command functions during the data link mode of operation. Maximum safe Mach (MSM) is represented by a red and white striped marker moving over the Mach tape. All of the tapes, digital counters and markers are actuated by servomotors. There is a total of seven servomotors in the MSSA indicator. These servomotors receive control phase voltage from the outputs of the seven servomagnetic amplifiers. They are located in the MSSA amplifier which was previously discussed in this chapter.

Exercises (A90):

1. What are the three displays on the Mach safe speed airspeed indicator?

2. How is command Mach and airspeed presented on the Mach safe speed airspeed indicator?

3. What is the purpose of the slew switches on the face of the Mach safe speed airspeed indicator?

4. How many servomotors are there in the MSSA indicator?

A91. Explain operating principles of the minimum safe speed g-section in the MSSA indicator.

Minimum safe speed (MSS) g-section. The MSS tape is located on the left side in the MSS g-section. It is positioned by a true angle-of-attack signal from the CADC. The range of the tape is from -10° to +25° angle of attack. The MSS tape is read against the lubber line. The 0 on the tape indicates that proper angle of attack is being maintained for normal flight. The area (see fig. 4-5) on the tape marked "MIN SAFE SPD" indicates MSS (minimum angle of attack) is being maintained for normal flight attitude. The cross-hatched area on the tape indicates that the aircraft speed is too slow. The triangle marked "FINAL" indicates MSS during final approach. The pilot flies the aircraft to the apex of the triangle for proper angle of attach while descending to the end of the runway. At the end of the runway, the pilot flies the aircraft to the base of the triangle to indicate proper flareout before setting the aircraft down.

Refer to figure 4-5 because it will help you to better understand the discussion on the operation of the MSS tape which follows. As the angle of attack of the aircraft changes, the rotor of the CX is positioned out of null with respect to the rotor of the MSS CT located in the indicator. When this condition occurs, a position error signal is sent to the stator windings of the CT. This resultant signal is induced into the rotor of the CT. It is then routed through the auxiliary amplifier to the damper adjust potentiometer (R1401). This minimum safe speed error is tapped off the wiper of R1401 and sent into the servomagnetic amplifier. The output of the amplifier is routed to the control phase of the MSS servomotor. The servomotor positions the MSS tape through a gear train to indicate the existing angle of attack of the aircraft. The rotor of the generator is mechanically coupled to the rotor of the servomotor. When the servomotor is running, a damping rate signal is routed from the generator through the amplifier and on to R1401. At this point, the MSS error signal is damped to prevent oscillation and overtravel of the MSS tape. R1401 serves as a sensitivity adjust for the MSS tape. The rotor of the servomotor also drives the rotor of the CT to an electrical null with the rotor of the CT. When the null condition is attained, the MSS servomotor stops running. The MSS tape remains stationary until the angle of attack of the aircraft is changed.

A mechanical friction clutch and some limit stops are included in the gearing. They are installed between the servomotor and the tape to prevent the tape from being driven from view by large error signals. The clutch slips when the motor attempts to drive the tape beyond its maximum range.

The g-tape in the MSS g-section is located to the right of the MSS tape. With this arrangement, the acceleration forces acting in a vertical direction can be read in relation to the aircraft angle of attack. The range of the g-tape is 0 to 7 g's. A digital counter located on the bottom of the MSS g-section indicates a digital readout of the tape in g's and tenths of a g. This gives the pilot a fine readout of g-forces acting on the aircraft.

The g-servoloop is functionally the same as the MSS servoloop with the exception that the g-tape servoloop does not have a damper adjust such as the MSS servoloop has (R1401). The g-tape is positioned by a signal from the g-sensor. However, there is no comparable signal used in the MSSA indicator. Knowledge of the MSS tape should enable you to understand the g-servoloop without further explanation.

970

Exercises (A91):

1. Why does the pilot fly the aircraft to the apex of the triangle marked "FINAL" on the MSS tape?

2. What is the purpose of R1401 in figure 4-5?

3. Why is the g-tape in the MSS g-section located to the right of the MSS tape?

A92. List the information displayed in the Mach section of the MSSA indicator and explain the purpose of different components of the MSSA indicator.

Mach section. The Mach section of the indicator displays three types of flight information. These are Mach, command Mach, and maximum safe Mach (MSM). Both Mach and MSM information are obtained in elecrical form from the aircraft CADC system. Command Mach may be developed manually by operating a slew switch on the face of the indicator. It can also be actuated automatically by command signals from a ground station through data link.

The Mach tape range is from 0.4 to 3.0 Mach. The Mach fine and course position error signals required to operate the Mach tape come from the Mach module of the CADC system. Figure 4-6 is a functional diagram of the Mach section.

The Mach fine and coarse position error signals are applied to the stator windings of the Mach fine and coarse CTs in the MSSA indicator. The electrical outputs from these CTs, which repeat the Mach error, are transmitted to the auxiliary amplifier in the MSSA amplifier. Here, they are passed through the diode switches. (The operation of the switching diodes was previously discussed in this chapter when we covered the auxiliary amplifier.)

The Mach error signal is then routed to the Mach servomagnetic amplifier, where it is amplified. The amplifier output is fed back to the indicator, where it is used to drive a motor-generator set. The motor mechanical output repositions the rotors of the Mach CT to null. The generator provides an electrical feedback to the auxiliary amplifier for rate damping.

During moderate accelerations, the rate of change in Mach is slow. The repositioning of the synchro (CT) rotors can closely follow the change in synchro input signals. The CT outputs are then near null, and the fine CT controls the servoloop. Its high sensitivity produces accurate nulling of the loop. However, during large accelerations, the CT errors are large. The fine CT output is then limited, and the coarse CT controls the servoloop. Its high sensitivity produces accurate nulling of the loop. The switching of control from fine to coarse CT is a function of the diodes in the MSSA amplifier.

The Mach servomotor positions the Mach tape through gearing. A clutch and stops are used to prevent overdriving the tape. The motor shaft rotation is also sent to a differential. There it is combined with a shaft rotation representing command Mach. The signal is then used to position the command marker at a point representing the relative values of the command Mach and the actual Mach of the aircraft. The Mach shaft rotation is also used to position the MSM input synchro in order to null the error in the MSM servo.

The CX that transmits the MSM signal is located in the pressure altitude (Hp) module of the CADC system. The signal is applied to a CT in the MSSA indicator. The resulting synchro error signal is then sent to the MSM servomagnetic amplifier through the auxiliary amplifier. The output of the MSM servomagnetic amplifier is returned to the MSSA indicator, where it drives a motor generator set. The motor then positions the MSM marker, through a gear train, to indicate the structural limits of the aircraft for the existing altitude that it is flying. At the same time, it positions the rotor of the CT back to an electrical null. The generator provides rate-damping feedback to the auxiliary amplifier. The MSM CT rotor is also geared to the Mach servomotor; consequently, the net output of the MSM CT represents the combination of these two signal errors.

The MSM servomotor positions a tape to which the MSM marker is attached. This marker is read against the Mach tape scale. The Mach tape is also in motion. Consequently, for the MSM to be read against this moving tape, the Mach information is added to the MSM information. This is done so that the MSM marker moves when the Mach tape moves. Mechanical stops prevent the MSM marker from being driven beyond the field of view; a slip clutch, included in the gear train between the MSM motor and the MSM marker, allows the motor to continue turning when the marker is stopped.

Figure 4-7 illustrates the principles of operation of the slew switch and data link. The command Mach counter and marker may be manually positioned by the slew switch. They can also be automatically set by a signal from data link. Which of these modes of operation is used depends upon the position of K1 and K2. The solenoids of K1 and K2 are controlled by the mode select switch. In the DATA LINE position, these solenoids are energized and the contacts are pulled down.

The command Mach slew switch is mechanically coupled to the wiper of resistor R1001 and to a cam. A bellows allows flexibility of a slew switch. It also prevents leakage of the gas and nitrogen mixture contained in the indicator. A 26-volt AC source is fed to the switch (S1001) from the power transformer when aircraft power is applied to the system. When the slew switch is in the neutral position, the 26-volt AC is routed through CR401 (in fig. 4-7), which converts the AC to DC voltage. This DC voltage is routed to the fixed phase of the command Mach servomotor. This locks the rotor and prevents it from drifting once the desired command

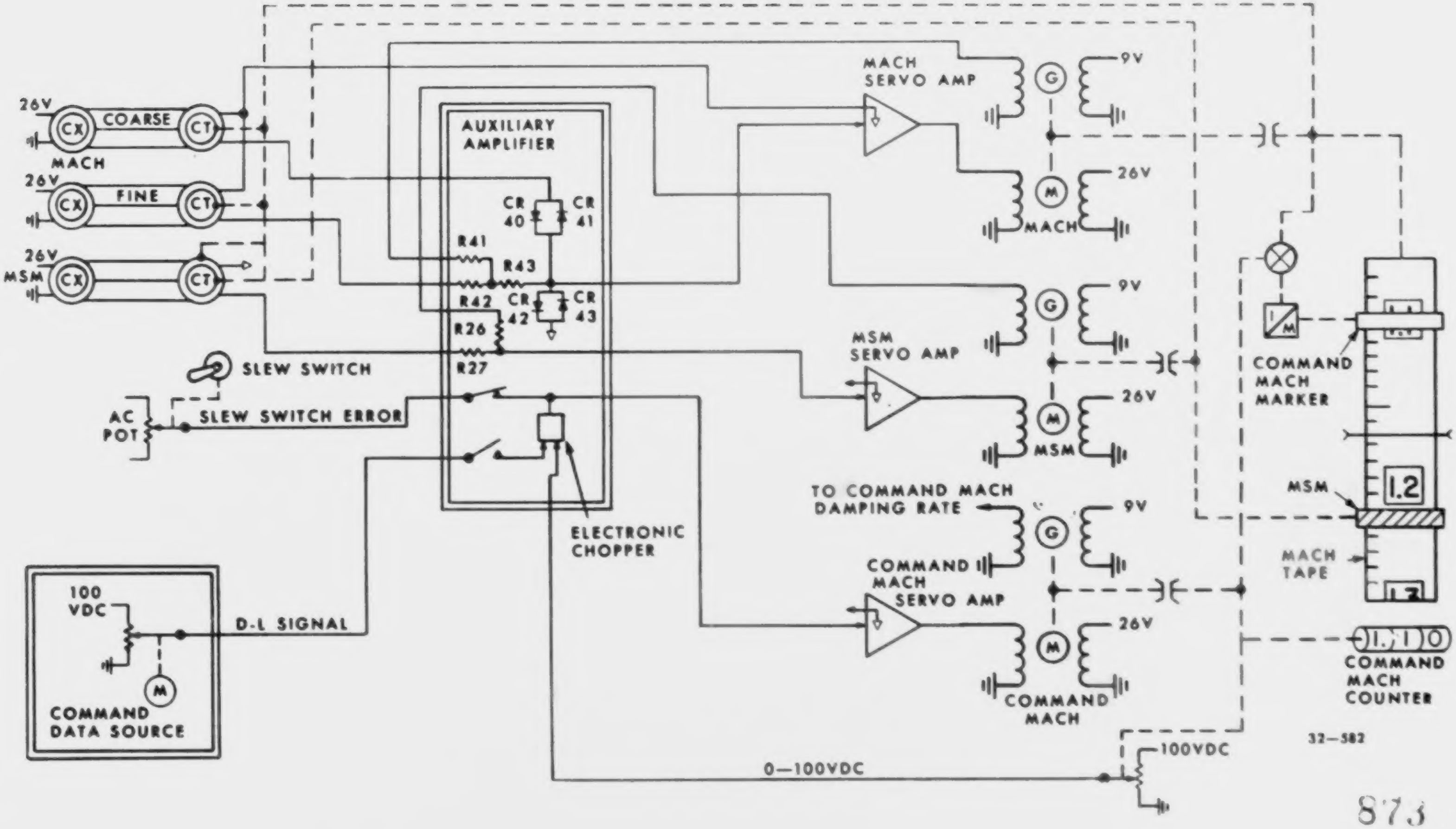
26V
CX
COARSE
CT
MACH
26V
CX
FINE
CT
26V
MSM
CX
CT
SLEW SWITCH
AC POT
SLEW SWITCH ERROR
AUXILIARY AMPLIFIER
CR 40
CR 41
R41
R43
R42
CR 42
CR 43
R26
R27
ELECTRONIC CHOPPER
100 VDC
M
COMMAND DATA SOURCE
D-L SIGNAL
0—100VDC
100VDC
MACH SERVO AMP
G
9V
M
26V
MACH
MSM SERVO AMP
G
9V
M
26V
MSM
TO COMMAND MACH DAMPING RATE
COMMAND MACH SERVO AMP
G
9V
M
26V
COMMAND MACH
COMMAND MACH MARKER
MSM
1.2
MACH TAPE
COMMAND MACH COUNTER
32—582

Figure 4-6. Functional diagram of the Mach section.

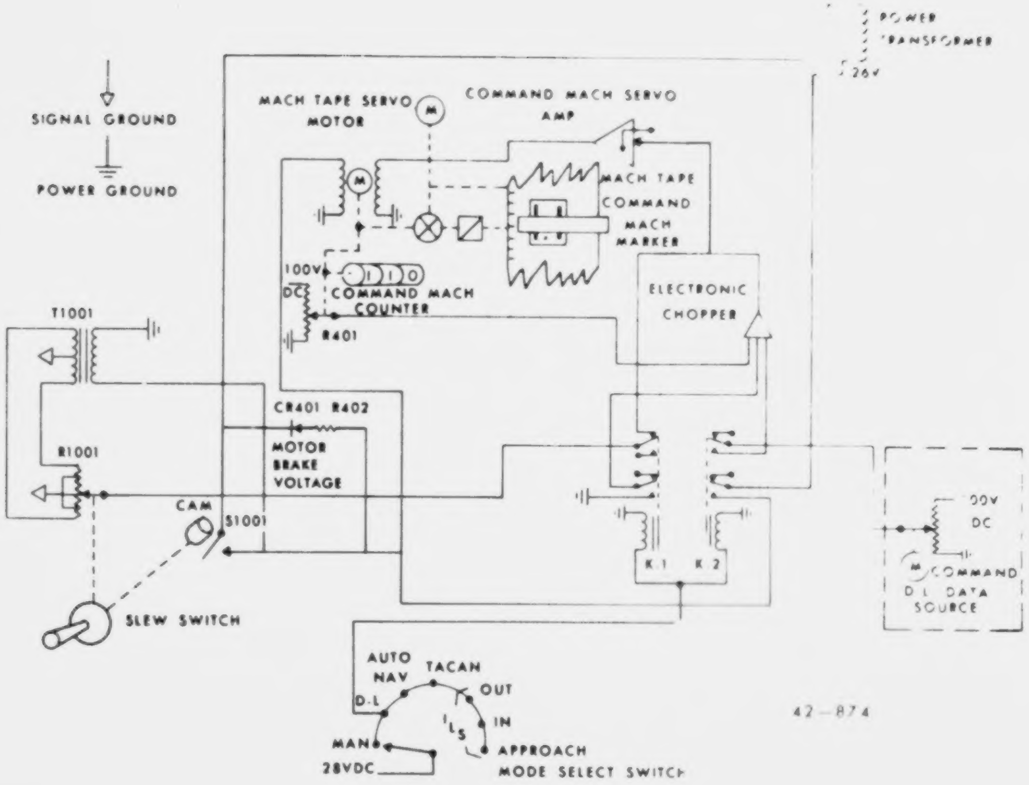
POWER
TRANSFORMER
26V
SIGNAL GROUND
POWER GROUND
MACH TAPE SERVO
MOTOR
COMMAND MACH SERVO
AMP
MACH TAPE
COMMAND
MACH
MARKER
100V
DC
COMMAND MACH
COUNTER
R401
ELECTRONIC
CHOPPER
T1001
CR401 R402
MOTOR
BRAKE
VOLTAGE
R1001
CAM
S1001
SLEW SWITCH
K1
K2
20V
DC
COMMAND
D L DATA
SOURCE
AUTO
NAV
TACAN
D-L
OUT
IN
ILS
MAN
APPROACH
28VDC
MODE SELECT SWITCH
42-874

Figure 4-7. Command Mach section.

Mach has been set. When the slew switch is moved from its neutral position, the cam closes S1001, and the 26-volt AC is sent to the primary winding of T1001. At the same time, the switch completes a short around CR401 and R402. This action removes the DC braking voltage from the rotor of the servomotor. The AC voltage is also applied to the fixed phase of the servomotor. The 26-volt AC power is induced into the secondary of T1001 and fed to R1001. The slew switch moves the wiper of R1001 from its zero output point. The resultant signal is sent to the Mach servoamplifier through the contacts of K1 in the auxiliary amplifier. Relay K1 is controlled by the external mode select switch. The output of the Mach servoamplifier is returned to the MSSA indicator to drive the command Mach motor. The motor positions the command Mach counter to indicate a direct reading of desired Mach. This same motor also positions the command Mach marker through a differential which combines Mach information with command Mach.

An intermittent mechanism (I/M) between the differential and the command Mach marker provides a memory device for command Mach. This counter-type mechanism memorizes a command Mach when the applied information is outside the range of Mach tape numbers that are in view. The intermittent mechanism also stores this information for the command Mach marker. This mechanism is operated like a counter when the marker reaches the limit of visibility and hits the window stop. The intermittent mechanism counts the number of revolutions of the command Mach gear train beyond the position indicated by the marker. The actual command Mach, however, is shown on the counter, which is independent of the intermittent mechanism. As the aircraft Mach approaches the command Mach, the input to the differential unwinds the intermittent mechanism. When the value of the inserted command Mach is finally visible on the Mach tape, the intermittent mechanism connects the gearing to the command Mach marker. The marker is then aligned with the number on the Mach tape corresponding to the command Mach.

In the command Mach data link mode, the command Mach counter is positioned automatically. This is done by a signal from a ground station through data link. Relays K1 and K2 are energized by 28-volt DC from the mode selector switch. Notice in figure 4-7 that a DC electrical signal representing command Mach is sent through a set of contacts of K2. The command Mach signal is compared with a DC signal from the wiper of the R401 in the MSSA indicator. The wiper of R401 is positioned by the command Mach servomotor. The difference between these two DC signals is the error signal. This signal is modulated by an electric chopper to a 400 Hz signal. (The operation of the electronic chopper was previously discussed in this chapter.) This 400 Hz signal is then routed to the command Mach servoamplifier. The output of this amplifier is then routed to the MSSA indicator to drive the command Mach motor-generator. The command Mach counter and marker is then set the same way as that previously discussed in slew switch operation. When in the data link mode, one set of contacts of K1 breaks the path of the slew error signal. The other set of contacts provides a ground for the electronic chopper. One set of contacts of K2 provides a path for the DC signal from data link. The other provides a path for the 26-volt AC source from the power transformer to the fixed phase of the command Mach servomotor.

Exercises (A92):

1. List the types of information displayed in the Mach section of the MSSA indicator.

2. What is the purpose of the motor-generator in the Mach section of the MSSA indicator?

3. How is overdriving of the tape prevented in the MSSA indicator?

4. What is provided in the MSM indicator to allow the MSM motor to continue running when the marker is stopped?

5. Why is a bellows used in the slew switch assembly?

6. Why is an intermittent mechanism installed between the differential and the command Mach marker?

7. What are the functions of the switches in the relay K1 that is used in the auxiliary amplifier in the MSSA amplifier?

8. What are the functions of the switches in relay K2 that are used in the auxiliary amplifier in the MSSA amplifier?

A93. State the information displayed in the indicated airspeed section of the MSSA indicator, and describe why the IAS marker and digital counter functions when the slew switch is placed in DETENT position.

Indicated airspeed section (IAS). The IAS section develops two types of information to be displayed. These are IAS and command IAS. The IAS information is obtained in an electrical form from the CADC system. Command IAS may be developed either manually by operating a slew switch, or automatically by command signals from a ground station through data link.

The range of the IAS tape is from 50 to 1000 knots. The IAS fine and coarse position error signals to operate the tape come from the impact pressure (Qc) module. This module is in the CADC system.

The operation of the IAS tape is functionally the same as the operation of the Mach tape. If you understood the operation of the Mach tape, you should have no difficulty following the IAS tape operation.

The commaand IAS counter and marker may be positioned manually by a slew switch, or automatically by a signal from a ground station through data link. The operation of command IAS is functionally the same as that previously discussed in command Mach.

The command IAS slew switch contains an extra feature. When the slew switch is moved to the side DETENT position, it closes a servoloop which automatically brings the command IAS marker to the lubber line and holds it there. The slew switch does this by connecting the output of the synchro to the input of the command IAS amplifier. This synchro, called the centering synchro, is set to electrical zero when the command IAS marker is at the lubber line. The synchro signal drives a motor, which positions the marker through a differential. Thus, the centering synchro provides a signal which represents the displacement of the marker from the lubber line. The signal positions the marker to the lubber line and keeps it there just as long as the slew switch is in the DETENT position. Also, the command IAS counter indicates a digital readout of IAS when the marker is at the lubber line.

Exercises (A93):

1. State the information displayed in the IAS section of the MSSA indicator.

2. Why does the command IAS marker slew to the lubber line when the command IAS slew switch is placed in the DETENT position?

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3. Why does the command IAS digital counter indicate a digital readout of IAS when the slew switch is placed in the DETENT position?

A94. State the purpose of the power transformer and servomagnetic amplifiers in the altitude vertical speed amplifier.

Operation of the Altitude Vertical-Speed (AVS) Amplifier. The AVS amplifier consists of a power transformer, four servomagnetic amplifiers, and an altitude auxiliary amplifier.

Power transformer. The AVS power transformer module consists of an iron core transformer with a single primary and five center-tapped secondaires. The primary winding is fed with 115-volt, 400 Hz, AC power by the aircraft electrical system. This AC power is tapped off the primary winding and sent to the four servomagnetic amplifiers. The required 62-volt, 400 Hz, AC reference voltage is tapped off the secondary windings. It is then routed to the four servomagnetic amplifiers. Excitation voltage for the motor generator units in the AVS indicator is supplied by the secondary windings of the power transformer.

Servomagnetic amplifiers. There are four servomagnetic amplifiers in the AVS amplifier. There are also four servomotors in the AVS indicator. These motors position vertical tapes and the digital counters. Consequently, four servomagnetic amplifiers are required for the operation of the AVS indicator. These amplifiers are identical to those previously described in this chapter when we were discussing the MSSA amplifier.

Exercises (A94):

1. State the purpose of the power transformer in the AVS amplifier.

2. State the purpose of the servomagnetic amplifiers in the AVS amplifier.

A95. Name the different sections of the AVS amplifier and explain their purpose and operations.

Auxiliary amplifier. The AVS auxiliary amplifier consists of several sections. These sections are the vertical-speed preamplifier and postamplifiers, quadrature rejection circuit, electronic choppers, switching diodes, and two relays which control the operation of the command altitude.

The first units to be discussed are the vertical-speed preamplifier and postamplifiers. The vertical-speed error signal is first sent through a single-stage transistor preamplifier. Then it is sent through a quadrature rejection circuit. This circuit is used for eliminating quadrature components of the signal from the preamplifier stage. They are components of the signal voltage that are 90° out of phase with the signal voltage. Then it is amplified again in a postamplifier, and from here the signal is routed to the vertical-speed servomagnetic amplifier. There it develops sufficient power to drive the vertical-speed servomotor in the AVS indicator.

The auxiliary amplifier circuits which process the vertical-speed signal are shown in figure 4-8. The vertical-speed signal is applied through pin 48 of the auxiliary amplifier connector to coupling capacitor C1, and then to the base of the preamplifier transistor Q1. The transistor is an NPN type is which the output signal voltage is taken from resistor R1 in the emitter circuit. The arrangement is similar to the vacuum-tube cathode follower. The output signal is coupled through capacitor C3 and isolating resistor R5 to the quadrature rejection circuit. Then it is coupled through C4 to the base of the postamplifier transistor Q4. There the output signal is taken from the collector and sent through C6 to pin 22 of the auxiliary amplifier connector. The signal is then applied to the servoamplifier. Operating power for transistors Q1 and Q4 is provided by the full-wave power supply in which silicon diodes CR2 and CR3 are the rectifiers, and the filter circuit is made up of R15, R14, C7, and C8. The DC voltage thus obtained is well regulated by Zener diode CR5 and a bleeder resistor.

The basic elements of the quadrature rejection circuit are shown in figure 4-9. The AC signal from the emitter follower Q1 is coupled through capacitor C3 to the quadrature rejection circuit. This circuit consists of Q2, Q3, choke L1, and related circuit components. The quadrature rejection circuit removes the quadrature voltages (voltages 90° out of phase with the signal voltage) from the signal voltage. The rejection circuit consists of demodulator Q2, modulator (chopper) Q3, and filter L1. Transformer T2 applies an AC voltage to the base of Q2. This voltage is in phase with the signal voltage applied to the emitter of Q2 and 90° out of phase with the quadrature component of the signal voltage. Thus, a maximum DC voltage is produced at the collector of Q2 from the signal voltage, whereas a minimum DC voltage is produced from the quadrature component. The DC voltage is coupled to the collector of Q3, which operates as a 400 Hz electronic chopper (modulator). The 400 Hz switching voltage is applied to the base of Q3 from Zener diode CR1. This diode shapes the 400 Hz sine wave from T2 to approximate a square wave. The AC voltage produced at the emitter of

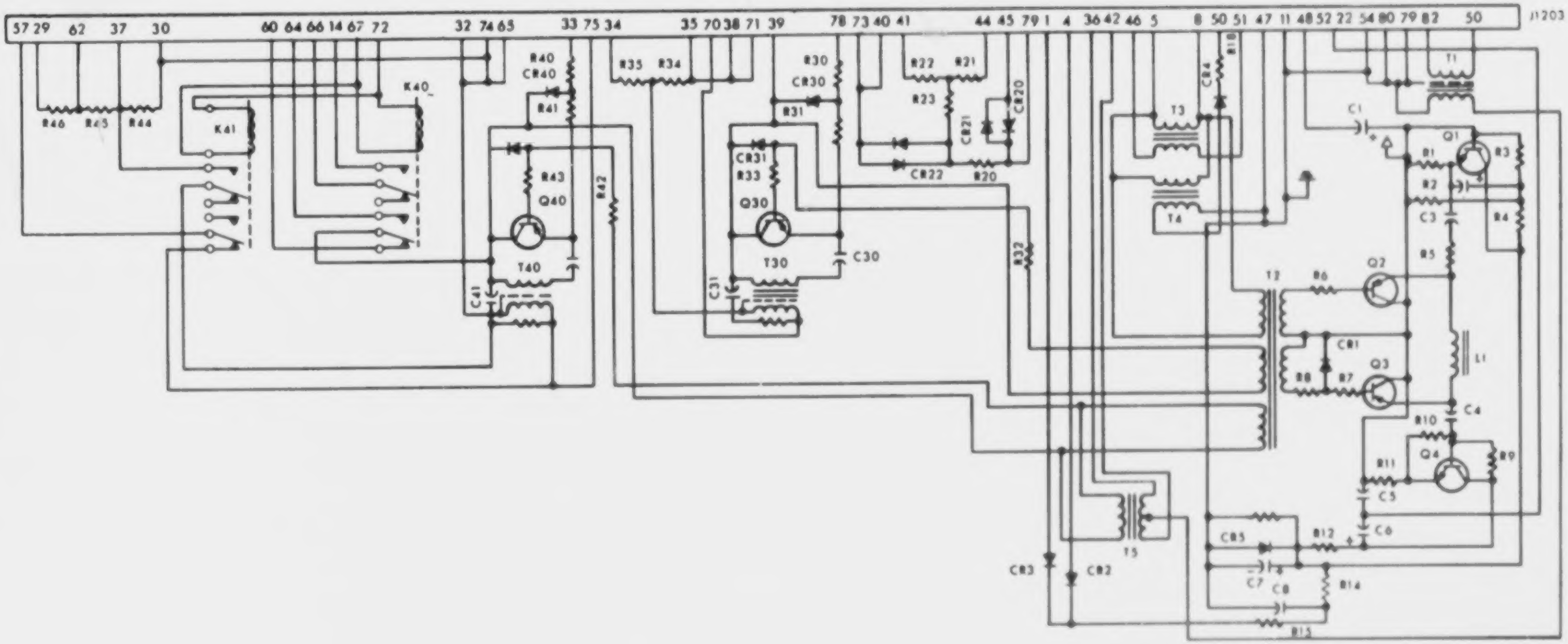

57 29 62 37 30 60 64 66 14 67 72 32 74 65 33 75 34 35 70 38 71 39 78 73 40 41 44 45 79 1 4 36 42 46 5 8 50 51 47 11 48 52 22 54 80 79 82 50
J1203
R46
R45
R44
K41
K40
R40
CR40
R41
R43
Q40
T40
C41
R42
R35
R34
R30
CR30
R31
CR31
R33
Q30
T30
C31
C30
R22
R21
R23
CR21
CR20
CR22
R20
R32
T3
T4
CR4
R18
T1
C1
Q1
R1
R3
R2
C3
R4
R5
T2
R6
Q2
CR1
R8
R7
Q3
L1
C4
R10
Q4
R9
R11
C5
C6
CR5
R12
C7
C8
R14
R15
T5
CR3
CR2

Figure 4-8. Altitude vertical-speed auxiliary amplifier.

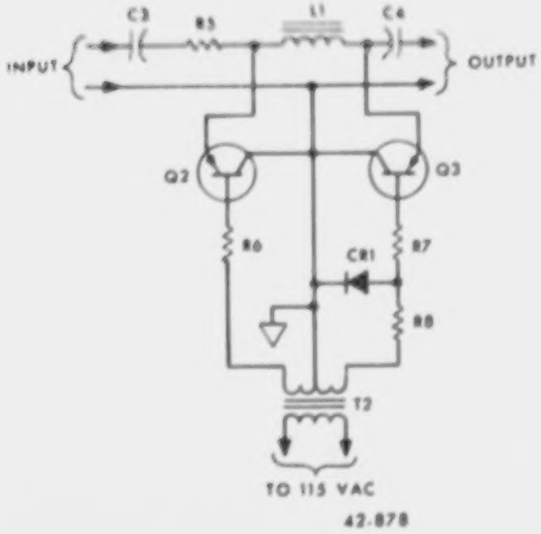

C3
R5
L1
C4
INPUT
OUTPUT
Q2
Q3
R6
CR1
R7
R8
T2
TO 115 VAC
42-878

Figure 4-9. Simplified vertical-speed quadrature rejection circuit.

Q3 reproduces the original signal voltage with most of the quadrature component removed.

The AVS indicator auxiliary amplifier contains two transistorized electronic choppers, so called because they perform the same function as the mechanical chopper. That function is to convert a DC error signal to a 400 Hz AC signal by a modulation process. The first of the two choppers is part of the command altitude servosystem. The second chopper is part of the target altitude servosystem. Both choppers operate in the same way.

The 400 Hz signal is induced into the circuit by T2, shown in figure 4-10. The transformer voltage comes from the AVS indicator power transformer module. This circuit operates the same (electrically) as the circuit shown in figure 4-3 and previously explained. Of course the source of the inputs differ and are shown in figure 4-10.

The AVS indicator auxiliary amplifier also contains a set of switching diodes in the sensitive altitude servosystem. This system employs coarse and find corrected altitude signals, which are combined in a single amplifier. For large altitude errors, both signals are effective in controlling the system. As the synchros approach null and the error becomes small, the switching diodes switch out the coarse signal. This allows the fine signal to drive the servosystem to the null position.

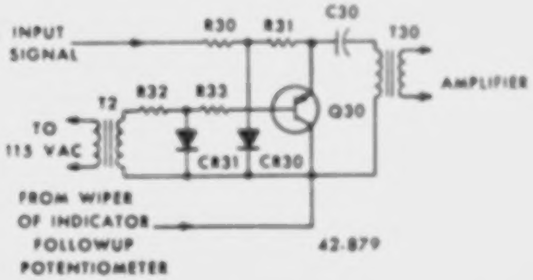

INPUT SIGNAL
R30
R31
C30
T30
AMPLIFIER
T2
R32
R33
TO 115 VAC
CR31
CR30
Q30
FROM WIPER OF INDICATOR FOLLOWUP POTENTIOMETER
42-879

Figure 4-10. Simplified electronic chopper circuit.

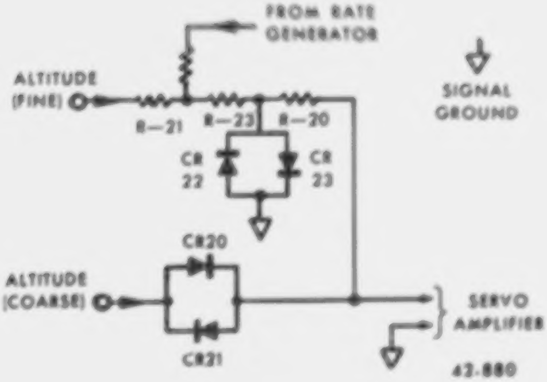

FROM RATE GENERATOR
ALTITUDE (FINE)
R-21
R-22
R-20
CR 22
CR 23
SIGNAL GROUND
CR20
ALTITUDE (COARSE)
CR21
SERVO AMPLIFIER
42-880

Figure 4-11. Simplified switching diodes circuit in the altitude servo.

The switching diode circuit, shown in figure 4-11, operates identically (electrically) to the circuit shown in figure 4-2 and previously explained. The sources of the inputs differ (see fig. 4-8).

The two relays (K40 and K41, shown in fig. 4-8) in the auxiliary amplifier, control the operation of the command altitude digital counter in the AVS indicator. When the relay contacts are deenergized, the digital counter is positioned by the slew switch. This switch is located on the face of the AVS indicator. The solenoids of the relays are energized by 28-volt DC. This DC signal comes from the mode select switch when it is in the DATA LINK position. When these relays are energized, the command altitude digital counter is positioned by a signal from a ground station through the data link receiver.

Exercises (A95):

1. What are the different sections of the AVS amplifier?

2. State the purpose of the quadrature rejection circuit in the AVS auxiliary amplifier.

3. State the purpose of the electronic chopper in the AVS indicator auxiliary amplifier.

4. In reference to figure 4-8, when would the two relays (K40 and K41) be energized?

A96. Cite the presentations on the altitude vertical speed indicator and describe aspects of indicator operation.

Operation of the Altitude Vertical-Speed Indicator (AVS). The AVS indicator receives signals from the CADC system in the form of synchro or rate generator signals. It presents vertical-speed (rate of climb) and pressure altitude information to the three vertical scale tapes. The indicator also receives inputs in the form of potentiometer signals which originate in the data link receiver. These signals are used by the indicator to present command altitude and target altitude on the two command digital counters.

The AVS indicator presents flight information in the three sections. These are the vertical speed (rate of climb), the sensitive altitude, and the gross altitude.

Vertical-speed section. Vertical speed is proportional to the rate of change in altitude. This signal is obtained from the pressure altitude rate module (Hpr) in the CADC system. A rate generator in the Hpr module provides an electrical output signal.

The signal is applied to the auxiliary amplifier module of the AVS amplifier. There it is compared with a signal from a followup potentiometer in the AVS indicator that represents the present servosystem position. The difference, or error signal, is amplified and passed through a quadrature rejector circuit. In this circuit, quadrature voltage components are removed. The signal is then fed to the vertical-speed amplifier module which drives a motor generator in the vertical-speed indicator. The generator provides rate damping feedback to the amplifier. The shaft rotation of the motor positions the wiper arm of the followup potentiometer. This is done so that the electrical output of the potentiometer, which represents the position of the servosystem, is equal to the signal representing the input information. The net input signal to the servosystem is now reduced to null.

The rotation of the motor-generator shaft also positions a marker. This marker is free to move vertically within the visible range of the indicator. This moving marker is read against a fixed vertical scale having a range of from 0 to 2000 feet per minute (fpm). By using the proper gear ratios from the servomotor to the marker, it indicates the vertical speed (rate of climb) of the aircraft. When the marker reaches the small window at the upper or lower extremity of the fixed scale, it is disengaged from the drive shaft by an I/M. An indication of vertical speed is still given beyond this point by a vertical tape. The tape gives numerical indications from 2,000 to 40,000 fpm, which appear in the upper window during climb and in the lower window during dive. The intermittent mechanism functions in the same manner as the one described in the Mach section of the MSSA indicator. The MSSA was previously discussed in this chapter.

Exercises (A96):

1. Cite the presentations on the AVS indicator.

2. Where does the AVS indicator receive its vertical speed signal from?

3. How long will the followup potentiometer transmit a rate damping feedback to the amplifier?

4. What protects the vertical speed marker when it reaches the extremes of the fixed scale?

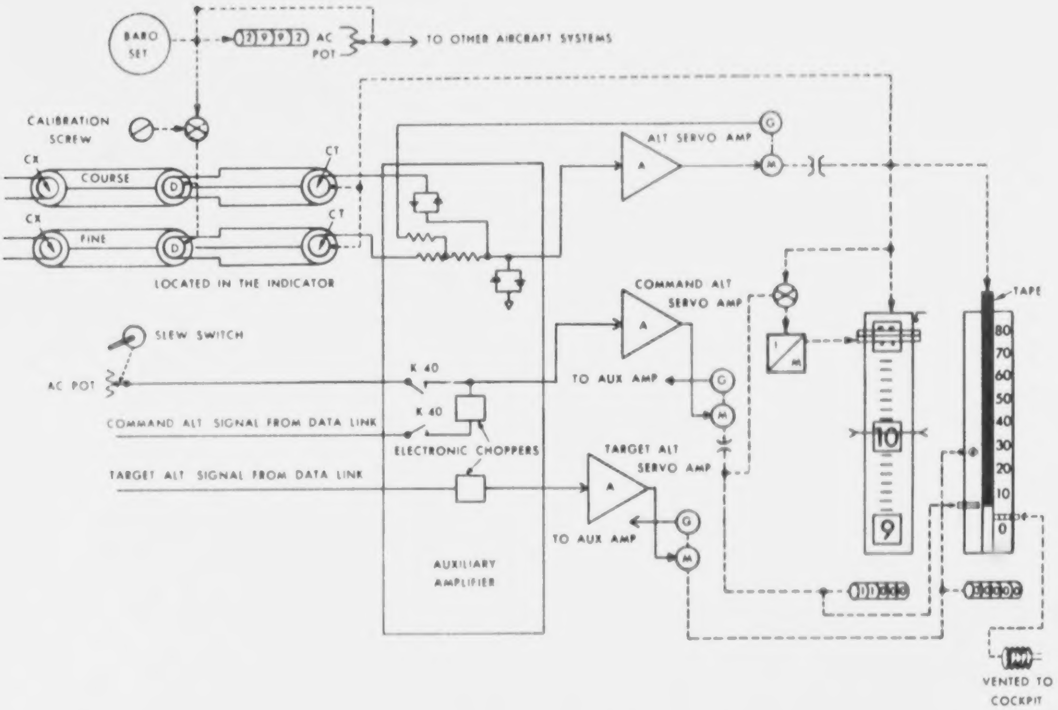
A97. State the information developed by the sensitive altitude section, cite the range of the sensitive altitude tape, and explain how an altimeter setting is made on the AVS indicator.

Sensitive altitude section. The sensitive altitude section displays two types of information. This information is altitude and command altitude. Altitude information is obtained in the form of an electrical synchro signal from the CADC. Command altitude is obtained from two sources. It may be set manually by operating a slew switch on the face of the AVS indicator, or it may be automatically set by command signals from a ground station through data link.

The range of the sensitive altitude tape is −1,000 to +80,000 feet. The tape is marked in increments of 100 feet and is read against a fixed horizontal reference (lubber line.)

The altitude fine and altitude coarse position error signals are supplied by outputs of the pressure altitude module (Hp) of the CADC. Figure 4-12 shows a simplified schematic of the altitude section.

Notice (fig. 4-12) that the fine and coarse error signals are sent to corresponding synchros in the AVS indicator through the barometric set differential synchros. The electrical outputs of these CTs, which repeat corrected altitude errors, are transmitted to the auxiliary amplifier or the AVS amplifier, where they are passed through the diode switches. (The operation of the diode switches was described previously in this chapter when we discussed the auxiliary amplifier.) The error signal is then routed to the servomagnetic amplifier. The output is sent back to the AVS indicator, where it drives a motor-generator. The motor mechanical output repositions the rotors of the fine and coarse CTs to null. This output also positions the altitude tape to the existing


BARO SET
2992
AC POT
TO OTHER AIRCRAFT SYSTEMS
CALIBRATION SCREW
CX
COURSE
D
CT
CX
FINE
D
CT
LOCATED IN THE INDICATOR
SLEW SWITCH
AC POT
K 40
K 40
COMMAND ALT SIGNAL FROM DATA LINK
ELECTRONIC CHOPPERS
TARGET ALT SIGNAL FROM DATA LINK
AUXILIARY AMPLIFIER
ALT SERVO AMP
A
G
M
COMMAND ALT SERVO AMP
A
TO AUX AMP
G
M
TARGET ALT SERVO AMP
A
TO AUX AMP
G
M
I
M
10
9
TAPE
80
70
60
50
40
30
20
10
0
VENTED TO COCKPIT

32-584

Figure 4-12. Altitude section simplified schematic.

altitude. The motor shaft is geared to a differential. In this differential the amplifier output is combined with a shaft rotation representing command altitude.

The barometric setting is numerically displayed on a digital counter. The counter is located in the lower left corner of the indicator. This setting is manually set with the knob marked "BARO." The range of the barometric scale is from 28.0 to 31.0 inches of mercury.

The BARO knob shaft is also geared to the rotors of the barometric CTs through a mechanical differential. The Hp input signals from the CADC represent uncorrected altitude. When the BARO knob is set to the barometric setting, it represents barometric pressure corrected to sea level. Therefore, the input signals to the fine and coarse CTs represents corrected altitude.

A calibration screw is located slightly to the right of the BARO knob under a shield. The calibration screw is used to adjust the altitude tape to field elevation with respect to the current altimeter setting. To make this adjustment, you rotate the BARO knob to the existing altimeter setting (local pressure reduced to sea level pressure). Then turn the calibration screw until the sensitive altitude tape reads field elevation (altitude). Because the BARO knob is geared to the wiper of a potentiometer, an electrical signal representing field elevation can be transmitted to other aircraft systems.

The command altitude counter can be positioned manually or by means of a signal from data link. The electrical signal representing command altitude is applied to a bank of relay contacts in the AVS indicator. The relays are energized in the DATA LINK mode, through an external mode selecting switch. The command signal operates a closed servoloop. The servoloop consists of a followup potentiometer, an electronic chopper, a command altitude amplifier, and a motor-generator set. The motor shaft rotation drives a counter which gives a direct reading of the command altitude. The shaft also drives one input shaft of a mechanical differential. The information fed mechanically to the other input shaft of the differential represents corrected (sensitive) altitudes. The output shaft of the differential positions a marker with respect to the sensitive tape. This marker indicates the command altitude. The position of the marker represents aircraft altitude plus command altitude. That is, it represents aircraft altitude with respect to the (moving) sensitive altitude tape which represents command altitude.

When the marker reaches the end of the field of vision, the intermittent mechanism between the differential output shaft and the marker stores the additional altitude information. This counter type of mechanism provides a memory to the command information. If a command is applied which is out of the range of the numbers, it is still necessary for the command servo to run to a null and repeat this information the command counter. The intermittent mechanism stores this information for the command marker by operating similarly to a counter. This action takes place when the marker reaches the limits of visibility and hits the window stop. Thus, the intermittent mechanism counts the number of revolutions of the command gear train made beyond the position indicated. The actual command altitude is read on the command counter. Then, as the aircraft approaches the command altitude, the input to the differential "unwinds" the intermittent mechanism. When the value of the command altitude is finally visible on the sensitive tape, the intermittent mechanism reconnects the gearing to the command marker. The marker now aligns itself with the altitude of the sensitive tape, which corresponds to the command previously set in.

The command marker and counter may be positioned manually by a slew switch located on the face of the AVS indicator. Positioning the slew switch up or down actuates a rate servo which consists of a potentiometer, a command amplifier module, and a motor-generator. Moving the switch displaces the potentiometer from the zero output position. The resulting electrical signal is sent through the closed contacts of K40 to the command amplifier. The amplifier output is sent to the command motor-generator. Here the shaft rotation of the motor positions the command counter and marker as in the automatic mode. Because the operation is now that of a rate servo, the generator signal damps the slew switch potentiometer signal. Thus, the command counter and marker are moved in the direction determined by the displacement of the slew switch.

Exercises (A97):

1. State the information developed by the sensitive altitude section.

2. Cite the range of the sensitive altitude tape.

3. What is the purpose of the motor that is operated by the servomagnetic amplifier?

4. How is the altimeter setting made on the AVS indicator?

5. List the components in the closed servoloop that is operated by the data link command signal.

6. Which component of the sensitive altitude sections stores information beyond the limits of the counter?

A98. State the information displayed by the gross altitude section, cite the AVS gross altitude range, and explain how the marker is prevented from being driven beyond the field of vision.

Gross altitude section. The gross altitude indicator section displays four types of information: altitude, command altitude, target altitude, and cabin pressure. Notice in figure 4-12, that altitude and command altitude information is obtained from the sensitive indicator system in the form of shaft rotations. An electrical signal representing target altitude is obtained from the data link system. The AVS indicator contains an aneroid to provide the cabin pressure altitude. The correct pressur altitude is geared to a thermometer-type vertical tape. The line between the black and white portions of this tape indicates the altitude on a fixed vertical scale. This indication provides a gross altitude reading. The complete altitude range, from sea level to 80,000 feet, is compressed to appear in its entirety on the fixed scale. Similarly, the command altitude shaft rotation positions a marker with respect to the same fixed vertical scale.

The electrical signal representing target altitude is applied to the auxiliary amplifier module of the AVS amplifier. It is used to drive a closed servoloop. This servoloop consists of an electronic chopper, a target altitude amplifier module, a followup potentiometer, and a motor-generator. The shaft of the motor positions a marker with respect to the fixed altitude scale. It also drives a counter which gives a direct reading of the target altitude. Mechanical stops are used to keep the marker from being driven beyond the field of vision.

The aneroid barometer in the AVS indicator is linked mechanically to a third marker. This marker indicates the cabin pressure in terms of pressure altitude on the fixed vertical scale.

Exercises (A98):

1. State the information displayed by the gross altitude section.

2. State the gross altitude range.

3. How is the marker prevented from being driven beyond the field of vision?

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4-2. Maintenance

In this section, we will be discussion the inspection, operational check, troubleshooting, and bench check of the vertical scale flight instrument system.

A99. State inspection and operational check requirements of the vertical scale flight instrument system.

Vertical Scale Flight Instrument System Maintenance. The vertical scale indicators are hermetically sealed units and are not repairable at intermediate level. If internal repairs are necessary, the indicators must be sent to an authorized overhaul depot. Intermediate level maintenance is normally limited to removal and replacement of the indicators.

The vertical scale amplifier consists of sealed modules that plug into the amplifier chassis. Maintenance is limited to removal and replacement of the complete amplifier or replacement of the plug-in modules.

Inspection. When you inspect the vertical scale indicating systems, check the indicators and the amplifiers. Check the indicators for security of mounting, cracked glass, proper lighting, and clarity of scales. Check the amplifiers for security of mounting and safety wiring of the mount locknuts. You normally perform these inspection items during the aircraft's hourly phase inspection.

Operational checks. An operational check is required on the vertical scale flight instruments any time a component is replaced or a malfunction is suspected. You can check the airspeed and altitude tapes for operation by applying pitot and static pressure (use an approved pitot-static tester) to the aircraft pitot-static system. The tapes should follow the readings of the pitot-static tester smoothly and accurately.

Check the minimum safe speed tape by attaching a protractor to the angle-of-attack vane and positioning the vane to positions specified in the applicable TO. The safe speed tape should agree with the vane positions. Check the command marker and counters by manually positioning the slew switches located on the front of the indicators. The counters and markers should move freely. The marker and counter reading should agree with each other.

Some aircraft have an additional feature called self-test. This feature consits of a switch with low and high positions. When the switch is actuated, it causes the indicator tapes to drive to specified readings. For example, on certain type aircraft, placing the self-test switch in the low position causes the pressure and gross altitude to drive to a particular altitude. The calibrated airspeed tape drives to 547 knots and the Mach tape indicates a particular Mach. The vertical speed tape indicates a climb. When the test switch is released, the indicator readings should return to normal. Placing the self-test switch in the high position checks the altitude and Mach tapes at higher readings. The self-test feature checks the vertical scale indicating system for operation and accuracy by receiving fixed ouputs from the CADC. The complete aircraft operational check is contained in the applicable aircraft TO.

Exercises (A99):

1. What are the vertical scale flight instrument inspection requirements?

2. When is an operational check required on the vertical scale flight instrument system?

3. During an operational check of the vertical scale flight instrument system, what items are checked and what method is used to check them?

B01. With a hypothetical faculty component and a wiring diagram, determine the malfunction, and state what is accomplished during bench check of vertical scale flight instrument system components.

Troubleshooting. If malfunction exists in the vertical scale system, you can locate the faulty components by analyzing the system malfunction. This is done by using the self—test switch and related test equipment. After the exact type of malfunction has been determined, you should refer to the system schematic to locate the faculty component. For example, while performing an operational check with the self-test switch, you find that the sensitive altitude and gross altitude disagree. By referring to figure 4-12, you can see that the sensitive altitude and gross altitude are connected by mechanical linkage in the indicator. You can see that the logical component to change would be the altitude vertical-speed indicator.

Let's refer to figure 4-7 for our next malfunction. When placing the flight director mode select switch to the DATA LINK position, you find that the command Mach is inoperative. The first step in troubleshooting this problem would be to check the command Mach in the normal position. If the marker and counter work normally in the manual position, the command Mach amplifier, servomoter, mechanical linkage are working as they should. By looking back at figure 4-7, you can see that the only possible causes left are K1 or K2, the command data source, connecting wiring, a faulty mode select switch, or the electronic chopper. By using a multimeter to make continuity and voltage checks, you can easily locate the malfunction.

All malfunctions are not this easy to locate. However, if you perform an operational check to determine the exact malfunction and then analyze the system schematic, your troubleshooting job will be much easier.

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Bench check. You can bench check the vertical scale flight instruments by using the appropriate test equipment. The testers are designed to simulate all inputs to the vertical scale instruments. Therefore, you can check each tape and counter for operation and accuracy by positioning the control dials to the settings listed in the applicable TO. Each tester has an internal amplifier similar to the aircraft vertical scale amplifiers. When checking the aircraft amplifer, the tester's internal amplifier is disconnected. The amplifier's outputs that are under test are then read on a known serviceable indicator.

The power requirement for the test equipment is 115 volts at 400 Hz and three phases. You must set the power selector switch to a position that corresponds with the input power.

Exercises (B01):

1. If the contacts of K1 are struck in the opposite position from that shown in figure 4-7, how would it affect the command Mach indication?

2. What is accomplished during a bench check of the vertical scale flight instrument system components?

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Angle-of-Attack/Stall Warning and Sextants

IN THIS CHAPTER, we examine the theory and operation of a combined angle-of-attack (AOA)/stall warning system. The system discussed is used on aircraft with and without a CADC. It is not used with vertical scale instruments; however, some of the components may be, because all stall warning and angle-of-attack systems work basically the same and serve the same purpose.

We also cover an optical navigation system which currently stands alone. The reliability of the sextant is such that no system has yet been devised to render this ancient method of navigation entirely obsolete.

5-1. Angle-of-Attack (AOA)

We will start with the angle-of-attack system. It provides additional information needed for precision bombing, gunnery, take-offs, and landing.

B02. Explain principles related to the angle-of-attack system.

Definitions. The angle-of-attack system provides the pilot with a measurement of total aircraft weight versus lift. It, along with the stall warning system, informs the pilot whenever the aircraft approaches a speed or an altitude at which it will no longer fly. It also indicates whether the aircraft is in the proper altitude for landing or for the best rate of climb.

Do you remember, from Volume 2, the forces which act upon an aircraft during flight? They are lift, thrust, drag, and gravity. Drag and gravity are natural forces. Thrust and lift are artificially created forces that enable an aircraft to overcome these natural forces and fly.

Daniel Bernoulli, a Swiss scientist, identified the law of physics that states "As the velocity of a fluid increases, its internal pressure decreases."

As an airfoil (wing) is designed to increase the velocity of airflow over its top surface, which, in turn, creates a decrease in pressure on the top surface of the airfoil. The decreased top surface pressure allows the higher pressure on the bottom side to lift the airfoil. There are two other important factors closely associated with lift. These are relative wind and angle of attack. We shall discuss these factors before continuing.

Relative wind. As an aircraft moves through the air, a factor called relative wind develops between the moving aircraft and the surrounding air. Relative wind is similar to the breeze that you experience when driving an automobile at high speed with your hand out the window. No matter which direction you turn or whether you travel uphill or downhill, the relative wind always seems to be coming toward the front of the automobile. In an aircraft, relative wind is parallel with and opposite to the flight path.

Angle of attack.. There is a hypothetical line from the center of a wing's leading edge to its trailing edge. This line is called the wing chord. The wing chord meets the relative wind at a slight angle. The angle is called angle of attack. Do not confuse angle with pitch angle. Pitch angle is the angle between the longitudinal axis of the airplane and the horizon.

The magnitude or lift is directly proportional to air density, wing area, airspeed, and angle of attack. Up to a point, you can control the amount of lift by varying any of these factors. For example, as airspeed decreases, you can increase the angle of attack to maintain a constant lift; however, with further decreases in airspeed, the angle of attack eventually becomes excessive, creating turbulence over the top of the wing and resulting in a stall. Similarly, if the airspeed increases, a smaller angle of attack is needed to maintain constant lift. Now that we have reviewed these principles, let's look at the angle of attack indicating and stall warning system.

Exercises (B02):

1. What is the purpose of the angle-of-attack/stall warning system?

2. Why does an airfoil produce lift?

3. What is a wing chord?

4. What is angle of attack?

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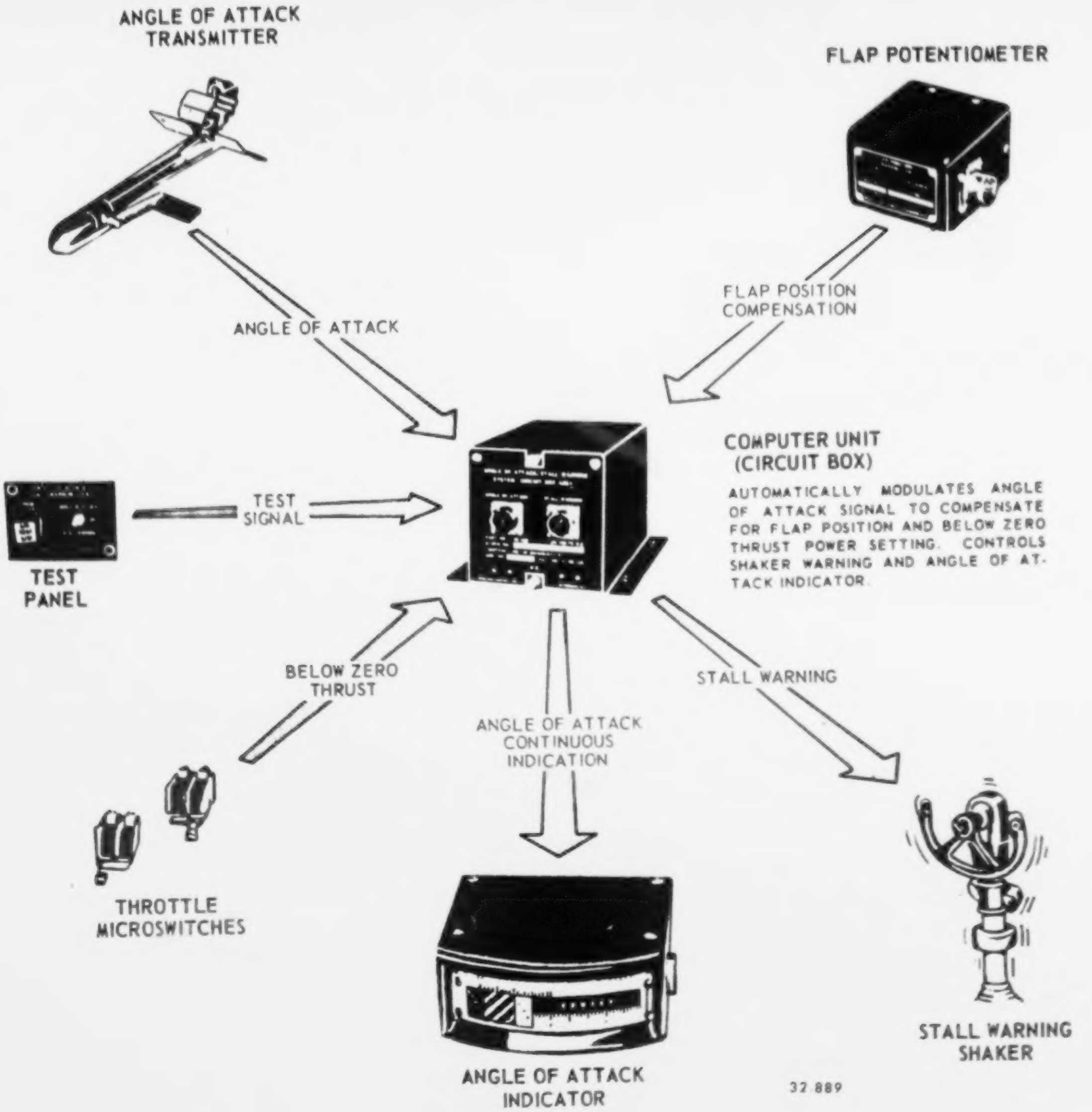
ANGLE OF ATTACK TRANSMITTER
FLAP POTENTIOMETER
ANGLE OF ATTACK
FLAP POSITION COMPENSATION
COMPUTER UNIT (CIRCUIT BOX)
AUTOMATICALLY MODULATES ANGLE OF ATTACK SIGNAL TO COMPENSATE FOR FLAP POSITION AND BELOW ZERO THRUST POWER SETTING. CONTROLS SHAKER WARNING AND ANGLE OF ATTACK INDICATOR.
TEST SIGNAL
TEST PANEL
BELOW ZERO THRUST
STALL WARNING
ANGLE OF ATTACK CONTINUOUS INDICATION
THROTTLE MICROSWITCHES
STALL WARNING SHAKER
ANGLE OF ATTACK INDICATOR
32 889

Figure 5-1. Angle-of-attack/stall warning system components.

B03. Identify the main sensing element of the angle of attack/stall warning system and state what module in the computer unit supplies the operating signal to the angle of attack indicator.

System Components. The angle-of-attack/stall warning system provides the pilot with a positive means for achieving the maximum performance of the aircraft under varying and uncertain flight conditions. It is particularly valuable during the landing and takeoff phases of assault operation. The system provides warning signals to the pilot of impending stall by visual means (a specific indication of the angle-of-attack indicator) and by physical means (actuation of the control column shaker). The system's main components are shown in figure 5-1. They include the following: angle-of-attack transmitter, angle-of-attack indicator, computer unit, test panel, flap potentiometer, stall warning shaker, and throttle microswitches. These units can all be replaced in the field.

Power source. The angle-of-attack/stall warning system operates from 28 volts DC. This is supplied from the aircraft bus. Separate circuit breakers are normally provided for the angle of attack and stall warning sections of the computer unit. A separate circuit breaker is also provided for the transmitter anti-ice heater element. The transmitter deicing heater elements are normally energized by the aircraft pitot heat switch.

Transmitter. The angle of attack transmitter is the sensing element of the angle-of-attack/stall warning system. This particular system uses a wing mounted type. It contains a movable van mounted on a rigid tubular support at the leading edge of the aircraft's wing. The movable van senses, and moves with, the airflow pattern. This airflow pattern varies with changes in wing angle of attack. The vane movements are mechanically coupled to the wipers of two potentiometers mounted at the rear of the assembly. The potentiometers translate the movement of the vane to corresponding electrical signals. The signal from one of the potentiometers is sent to the angle-of-attack section of the computer unit. The signal from the second potentiometer is sent to the stall-warning section of the computer unit.

In other angle of attack systems, the transmitter is mounted on the side of the fuselage and may provide input signals to bombing systems or fire control (gunnery) systems.

Angle-of-attack indicator. The angle-of-attack indicator shown in figure 5-1, provides the pilot with a continuous visual presentation of the sircraft angle of attack. The horizontal dial is calibrated from 0.9 to 1.4 times Vs (stall speed) in the low-speed range. The dial is also color coded to provide a quick reference for particular flight requirements. Signals to operate the indicator are supplied from the angle-of-attack module in the computer unit. Dampening of the DC milliameter pointer movement is provided to prevent major oscillations in pointer movement when flying in turbulent air.

A round dial angle-of-attack indicator is used in some systems. Also, the vertical scale system you studied in the previous chapter is used in place of this style of indicator. The scales of the different styles of indicators differ slightly. Whether it indicates in units of angle-of-attack or percent of lift (as some do), index markings are usually provided to show optimum angle-of-attack for maximum range and maximum endurance. Also, an approach index identifies the best flap compensated approach indication.

Exercises (B03):

1. What is the main sensing element of the angle-of-attack/stall warning system?

2. What module in the computer unit supplies the operating signal to the angle-of-attack indicator?

B04. State the type circuitry incorporated in the angle-of-attack module and name the component of the angle-of-attack/stall warning system that compensates the system for added lift of the wing flaps.

Computer unit. The angle-of-attack/stall warning system computer unit consists of a compact enclosure, housing four plug-in modules, and two chassis-mounted potentiometers. It contains the principal electronic circuitry of the angle-of-attack/stall warning system. Two of the modules and one of the potentiometers are for the angle of attack function; the other two modules and potentiometer are for the stall warning function.

The angle-of-attack module contains components of a resistive bridge circuit. This circuit includes the angle-of-attack potentiometers in the AOA transmitter and flap-position transmitter, as well as the chassis-mounted angle-of-attack potentiometer (part of the throttle input circuit) in the computer unit. The angle-of-attack indicator is electrically connected across the bridge and indicates the degree of bridge balance. Thus, the reading of the indicator depends upon the angle of attack as measured by the AOA transmitter and the flap position as measured by the flap-position transmitter. The throttle input potentiometer is a calibrated fixed resistance. It is bypassed when the throttles are open and is inserted in the bridge when any throttle is closed. The added resistance corrects the indicator reading, compensating for the decreased lift of the engine idle condition.

The stall warning module contains components of a sensitive electronic threshold circuit. The circuit includes the stall warning potentiometers in the AOA and flap-position transmitters and the chassis-mounted, stall warning potiometer (part of the throttle input circuit) in the computer unit. The stall warning module controls the pilot's control column shaker. When a point of impending stall is reached (as determined by the angle of attack and the flap and throttle positions), the threshold circuit switches change position to actuate the control column shaker and thus warn the pilot of the impending stall.

The angle-of-attack and stall warning test modules contain circuits that provide the system with a simple confidence check capability. All electrical connections between the computer unit and other components of the system are made through the two multiple connectors mounted on the front panel of the unit.

Test panel assembly. The test panel assembly consists of a push-to-test indicator lamp assembly and a three-position, spring-loaded (center OFF) toggle switch. The indicator lamp is designated by "A/A TEST S/W" printed on the lens. The toggle switch labeled "ANGLE OF ATTACK/STALL WARNING." When the toggle switch is pushed to either of the two test positions, the indicator lamp should remain off. If the indicator lamp lights, it indicates that the circuitry under test is defective.

The computer and test panel assembly discussed here are peculiar to this specific system. Different types of aircraft will have computers tailored to their specifications.

Flap-position transmitter assembly. The flap-position transmitter assembly houses two potentiometers. These are mechanically linked to the wing flap torque tube. The wipers of the potentiometers are positioned in accordance with the position of the wing flaps. These potentiometers compensate the system for the amount of lift provided by the flaps. This lift is not measured by the wing transmitter.

Exercises (B04):

1. What type of circuitry is incorporated in the angle-of-attack module?

2. Name the component of the angle-of-attack/stall warning system that compensates the system for the added lift of the wing flaps.

B05. Locate the control shaker and identify the component that adds the resistance to the fixed potentiometer.

Control column shaker. The control column shaker (stall warning shaker) is also shown in figure 5-1. It consists of an unbalanced, circular weight that is driven by a DC motor. Both the motor and the weight are enclosed in a circular metal housing. This housing fits around the pilot's control column. The DC motor is controlled by the angle-of-attack/stall warning system and is energized to indicate an impending stall. When the motor is energized, a buffeting motion is imparted to the control column by the rotating weight, thereby shaking the control column.

Throttle input switches. For simplicity of explanation, we shall use for our example a twin-engine aircraft. The throttle input switches are lever-actuated switches located in the control quadrant. Two of the switches are actuated by the left throttle. The other two are actuated by the right throttle. One of the switches actuated by the left throttle is connected in series with one of the switches actuated by the right throttle; these switches are connected in parallel with one of the chassis-mounted potentiometers in the computer unit. This forms a throttle input circuit. The remaining two throttle switches and the other potentiometer in the computer unit are wired in the same way to form a second throttle input circuit.

One throttle input circuit forms part of the angle of attack circuit, and the other forms part of the stall warning circuit. The throttle input circuits are connected in series with the ground legs of the two flap-position potentiometers. When both throttles are open, the four switches are closed. The throttle input circuits supply ground directly to the flap-position potentiometers. Thus, the degree of open throttle has no effect on the angle-of-attack/stall warning system. However, when either throttle is closed (idle condition), one of the switches paralleling each of the potentiometers is opened. Thus, the potentiometers are connected in series with the flap-position potentiometers. This increased resistance compensates the system for the decreased lift of the idle condition.

Exercises (B05):

1. State where the control shaker is located.

2. The resistance of the fixed potentiometer in the computer unit is connected in series with the wing flap potentiometers when the engines are at idle. Identify what component in the system adds this resistance.

B06. Describe why it is necessary to compensate the angle-of-attack/stall warning system for positioning of the flaps and idle condition of the engine and state the magnitude of the voltage output from the stall warning module that energizes the control shaker.

System Operation. The positioning of the AOA transmitter ahead of the leading edge of the wing causes the movable, pivoted vane to immediately sense and follow any change in the surrounding airflow pattern. The airflow pattern, in turn, is determined by the angle of attack of the wing. Thus, a change in angle of attack will cause a corresponding change in the position of the wing transmitter vane. Movements of the vane are mechanically linked to the shaft of two tandem-mounted potentiometers so that the positioning of the wiper arms is determined by the angle of attack. The output signal from one of the potentiometers is applied to a sensitive bridge-type measuring circuit, which supplies the angle-of-attack signal to the angle-of-attack indicator. The other potentiometer is connected to a threshold detection circuit, which actuates at a predetermined angle of attack that corresponds to the point at which an impending stall warning (control column shaker actuation) is given to the pilot.

The input signals from the two AOA-transmitter potentiometers (angle of attack and stall warning) are applied to the computer unit together with flap and throttle position information signals. The latter input is necessary because the AOA transmitter is not affected by changes in lift due to flap positioning or engine idle conditions. As we indicated previously, the flap-position transmitter assembly contains two potentiometers whose wipers are positioned by the wing-flap torque tube. Each of these potentiometers is connected to ground through a throttle switch arrangement consisting of two series-connected switches in parallel with a potentiometer. When both throttles are open, the switches are closed, and the wing-flap potentiometers are connected directly to ground. When either throttle is closed, the associated switches open and the throttle potentiometers are then connected in series with the flap-position potentiometers. Lowering the flaps decreases the resistance of the flap-position potentiometers. This decrease in resistance brings the inputs to the computer unit closer to ground potential and thereby compensates the system for the decreased lift of the idle condition.

Notice that a safety margin is provided by compensating the system for two idle engines when only one throttle is closed. Thus, the angle-of-attack system (and the associated stall warning system) is accurate and usable with all flap and throttle positions. The output signal from the angle-of-attack module is applied directly to the pilot's angle-of-attack indicator. The output of the stall warning module is a 28-volt DC signal. The signal energizes the control column shaker when the angle of attack is reduced to the point at which the impending stall indication should be produced.

The control column shaker circuit is completed to electrical ground by either or both of two switches associated with the left main landing gear. These switches are normally closed and are open only when the weight of the aircraft is on the landing gear. Thus, the control column shaker is disabled whenever the aircraft is on the ground but becomes operational in the air.

Remember that in the computer unit, there is not only the angle-of-attack module and the stall warning module which contain the measuring circuits for the respective system functions, but also the angle-of-attack and stall warning test modules, which contain the self-test circuits. These latter modules, in conjunction with the test panel assembly, provide the means for a confidence check of the entire system. This check can be made at any time.

Exercises (B06):

1. Describe why it is necessary to compensate the angle-of-attack/stall warning system for positioning of the wing flaps and idle condition of the engines.

2. State the magnitude of the voltage output from the stall warning module that energizes the control column shaker.

B07. Name the four modules of the computer unit and explain particular procedures used in ground testing.

Ground Testing. Ground testing of the angle-of-attack/stall warning system may be accomplished using the test panel assembly. Remember, the readings and conditions of the test discussed here are of a typical system. Your own testing may be different, depending on the aircraft in which the system is installed. In all cases you should consult the applicable aircraft TO for the proper ground test procedures.

The first test we shall discuss is an operational check of the AOA transmitter deicing system. On most aircraft the DC power to operate the vane and nose cone heaters is supplied by the pilot heat switch. Your first step in checking the heaters should be to remove the pitot tube covers. Two instrument specialists will be required to safely perform the remainder of the test. If the heaters in the wing transmitter are energized for more than a few minutes, the vane and nose cone will become hot enough to inflict a serious burn. With this thought in mind, let's proceed with the check. Station one specialists in the aircraft cockpit and the other are the AOA transmitter. When the specialist in the cockpit sets the pitot heat switch to ON, the other specialist should touch the nose cone and vane lightly to verify that they are becoming warm. After the verification, the specialist should return the pitot heat switch to OFF. Wait a few minutes for the pitot tubes to cool; then reinstall the pitot covers.

The reminder of the tests use the built-in self-test provisions of the system and include routine functional checks. If failures are encountered in performing the following test, troubleshooting and corrective action must be taken. Before proceeding with the test, make sure that 28-volts DC power is available to the system and that all circuit breakers for the system are set. Perform the following steps:

(1) Raise the wing flaps to the full UP position.

(2) Open all throttles as far as the stops will permit.

(3) Press the A/A TEST S/W lamp on the test panel assembly. The lamp should light.

(4) Set the angle-of-attack/stall warning switch on the test panel assembly at ANGLE OF ATTACK (up). The angle-of-attack indicator pointer should deflect smoothly to read 3.0 ± 0.1 on the cruise index of the scale. The red A/A TEST S/W lamp should not light. If the angle-of-attack indicator reading is not within the specified tolerance, recalibration of the angle-of-attack circuit is required. Refer to the applicable aircraft TO. If the red A/A TEST S/W lamp lights, a defect in the angle-of-attack circuit is indicated.

(5) With the angle-of-attack/stall warning switch still set at ANGLE OF ATTACK, close the left throttle. The needle of the angle-of-attack indicator should deflect to the left a distance of three small divisions plus or minus one needlewidth.

(6) Open the left throttle; repeat step 3, using the right throttle.

(7) Set the angle-of-attack/stall warning switch at STALL WARNING (down). The pilot's control column shaker should actuate and the red A/A TEST S/W lamp should not light. If the control column shaker is not actuated, recalibration of the stall warning circuit is required. Refer to the applicable aircraft TO. If the red A/A TEST S/W lamp lights, a defect in the stall warning circuit is indicated.

Exercises (B07):

1. State how many avionics instrument specialists are required to safely check the wing transmitter anti-ice heater.

2. What type of defect is indicated if the A/A TEST S/W lamp on the test panel assembly lights when the test switch is placed to the angle-of-attack position.

B08. Describe the method of checking the flap and stall warning potentiometers and identify the operation that must be performed if a defective module in the computer is replaced.

Maintenance. Normal flight line maintenance of the system consists of removing and replacing defective components. These defective system components are isolated by making wiring and voltage checks with the use of a multimeter and the built-in test function. However, we shall also discuss some component maintenance that can be performed on the system. You must again remember that you must consult the applicable aircraft TO before performing any maintenance on the system.

If you determine during routine troubleshooting that the angle-of-attack indicator is defective, it must be replaced. The indicator is a sealed instrument and must be sent to a depot for any internal repairs.

You can check the wing mounted AOA transmitter potentiometers without removing the transmitter from the aircraft, but for this check you must have a service-able ohmmeter. Make sure that no electrical power is applied to the system. Disconnect the two electrical connectors from the computer unit. Using the ohmmeter, measure the resistance between pins A and C of the aircraft cable connector that mates with the angle-of-attack connector on the computer unit. Resistance should be 1400 ohms ± 10%. Connect the ohmmeter between pins A and B of the same connector. Have someone rotate the AOA transmitter vane slowly throughout its range. The ohmmeter reading should vary smoothly from minimum to maximum resistance.

The stall warning potentiometer may be checked in the same manner as that described for the AOA transmitter potentiometers. Connect the ohmmeter between pins D and F of the electrical connector that mates with the stall warning connector on the computer unit. The resistance should be 1400 ohms ± 10%. Connect the ohmmeter between pins D and E of the same connector. Have someone move the vane transmitter throughout its range. Verify that the ohmmeter reading varies smoothly from minimum to maximum resistance.

When one or more modules of the computer unit are suspected of being defective, replace then with serviceable modules. If the system functions normally after a module replacement, a defect in the suspected module is verified. To gain access to the modules, loosen the fasteners on the computer unit. Withdraw the module assembly from the computer unit housing. You can remove any individual module by removing its securing screw (accessible from the bottom of the assembly) and carefully unplugging the module from the printed circuit board. Installation of the computer unit modules is the reverse of the removal procedure. Remember, when these modules are replaced, accurate test readings may not be obtained unless the module is calibrated in the system under test. You must recalibrate the system in accordance with the applicable aircraft TO whenever any unit in the system is replaced.

Exercises (B08):

1. State the method for checking the flap and stall warning potentiometers.

2. Identify the operation that must be performed if a defective module in the computer is replaced.

5-2. Sextants

Today's modern aircraft are often required to fly great distances on their assigned missions. These missions may require them to fly across oceans, at night or above the clouds. Land may not be seen for many hours. Although sophisticated electronic and gyroscopic navigation systems can guide them precisely to their destinations, there are times when these systems cannot be used. An electrical power failure or component failure can render them useless. Also, in times of war, it may be unwise to inform the enemy of the location of our aircraft by using radio or radar navigation systems. Such ground based navigational aids such as TACAN, DOPPLER, and glideslope may not be available.

Still, the flight crew must have some means of determining their exact location in these situations. At other times the crew must know exactly how much the wind is affecting their direction of travel. Without this knowledge, they could become lost or find that they are unable to reach their destination.

Over the years, several instruments have been developed to keep the flight crew informed as to where they are and in what direction they are going. Only the time-proven ancient marine instrument, the sextant, has survived. It is an astronomical optical instrument use for measuring angular distances of celestial bodies in determining latitude and longitude.

Before discussing the sextant, we need to understand the principles of light and some optical devices.

B09. State the speed of light and the angle of incidence and reflection.

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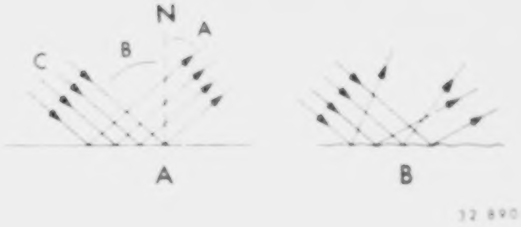

Figure 5-2. Reflection of light.

Principles of Light. There are many things about light which you already know. To most of us light is instantaneous. Your turn it on and there it is. No time delay occurs. This is not surprising, considering that the speed of light is equal to a distance of approximately eight times the circumference of the earth per second. Light travels at approximately 186,000 miles per second.

Reflection. Unless reflected or otherwise disturbed, rays of light travel only in a straight line. A ray is a very thin thread of light leaving a small point source. A number of light rays parallel to each other and close together form a light beam. You also know that light can be reflected. Almost any smooth surface reflects light. Examples of this are mirrors, water, and polished metal. The smoother the surface, the better it reflects the light. Figure 5-2 shows you why this is true. Notice that when the light strikes the smooth surface, in detail A, it is reflected without any change. Off the rough surface, the light rays are scattered. This is shown in figure 5-2, detail B. Light rays leave a smooth surface at the same angle at which they strike it. The angle (B) between the ray of light (C) striking a surface and a line (AN) drawn at a right angle (perpendicular) to the surface is called the angle of incidence. The line drawn perpendicular to the reflecting surface is called the normal. The angle (A) between rays of light leaving the reflecting surface and the normal is called the angle of reflection. We can say that in reflection, the angle of incidence equals the angle of reflection.

Exercises (B09):

1. State the speed light travels.

2. Write the angle of incidence.

3. Write the angle of reflection.

B10. Define refraction and angle of refraction and state the purpose of lenses and type of lens used to converge light.

Refraction. Now let's discuss something that might be new to you. Light travels more slowly through some materials than it does through others. Because of this it is possible to bend the beam of light. Let's use marching troops as our example. Refer to figure 5-3. In detail A, assume that troops are marching from a paved area directly into a plowed field. As the troops move into this field, they tend to slow down. This results in the troops bunching more closely together. They still continue to march in a straight line. Now look at detail B of the same figure. Suppose that the troops move from the pavement into the plowed field at an angle. The men who move into the field first will slow down while those on the pavement will not. The whole body of troops swings slightly to the right. The same thing happens in the case of light. For example, light travels about one and one-half times faster in air than it does in ordinary glass. Look at figure 5-4, detail A. It shows light as it passes directly through the glass. Detail B of this same figure shows the same beam of light when it strikes the glass at an angle.

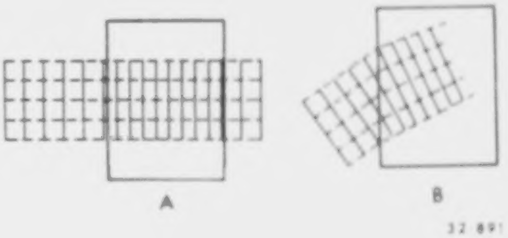

Figure 5-3. Troops marching from one medium to another.

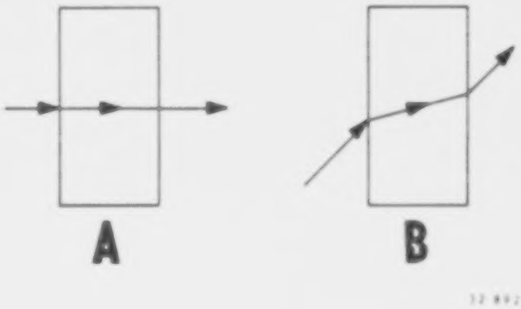

Figure 5-4. Path of a light beam through glass.

When light is sent at an angle from one material to another more or less dense, it is bent. This bending is called refraction. The best example of refraction occurs when you place a straight stick into water at an angle. The stick no longer appears straight. It appears to be bent at the waterline. When light enters a more dense material at an angle, it is refracted (bent) toward the normal. When it passes through a less dense material, it is refracted away from the normal. The normal, in this

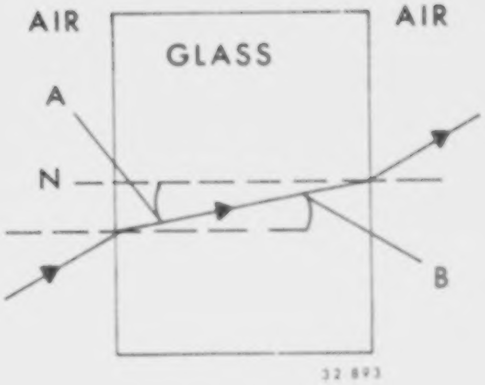

Figure 5-5. Refraction of light through glass.

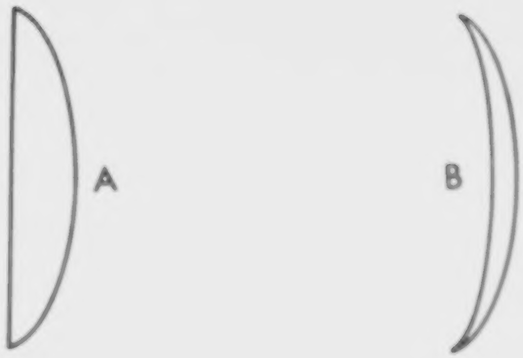

Figure 5-7. Two types of converging lens.

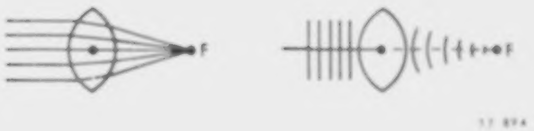

Figure 5-6. Focusing light with a convex lens.

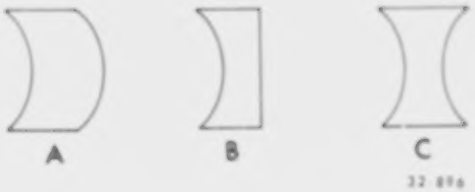

Figure 5-8. Three types of diverging lenses.

case, is a line drawn perpendicular to the surface where the two materials join. Look at figure 5-5. Notice that as light passes from air into glass it is bent toward the normal (N). As it passes from glass back into air, it is bent away from the normal. The angle (at A or B) between the light ray in the glass and the normal is called the angle or refraction. Let's apply these principles of light to lenses and prisms.

Lenses. The purpose of a lens is to refract rays of light. Lenses are made in a variety of shapes and sizes and affect light in various ways. Some concentrate (focus) the light rays at a given point. These are the convex lenses. An example of this type of lens is shown in figure 5-6. Note that it is a double-convex type. The point where all light rays meet is the principle focus of the lens. Other types of converging lenses are shown in figure 5-7. Detail A is the plano-convex type. Detail B is the converging meniscus type. Other types of lenses spread light rays. These are concave lenses. Figure 5-8 shows three common types of diverging lenses: the convex-concave, detail A; the plano-concave, detail B; and the double-concave, detail C.

Exercises (B10):

1. Define "refraction."

2. Define the "angle of refraction."

3. What is the purpose of lenses?

4. What type of lens is used to converge light?

B11. State the use of prisms.

Prisms. The prism is another optical device. It is designed to refract light rays. In this sense we can say that lenses and prisms are basically the same. Lenses are primarily used to refract light rays. The prism is used to bend light rays. The prism is made of glass and is basically triangular in shape. Figure 5-9 illustrates a typical prism in three positions. In detail A, it acts as a mirror to bend the light rays 90°. Detail B shows the prism as it transmits the image in the same plane but inverted. The image in each case is the small arrow. In detail C, notice that the prism has bent the light rays 180°. Let us now put these lenses and prisms to use.

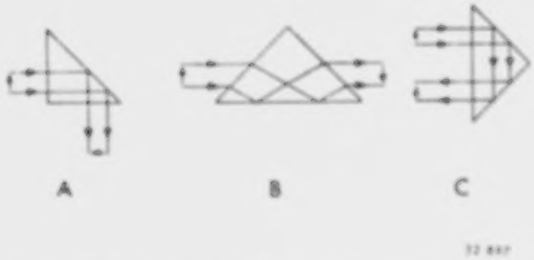

Figure 5-9. Refraction and reflection of light with prisms.

Exercises (B11):

1. What are prisms used for?

B12. Explain the use of the sextant.

Now we can discuss the sextant and sextant mount. We will also discuss the sextant and sextant mount operation and maintenance.

The Periscopic Sextant System. Since the sextant was first designed, many refinements have been added to it. These include the telescope and sighting devices. An artifical hoziron has also been added. Let's define the imaginary line which exists at eye level. It is a line that is parallel to the surface of the water or to the ground surface. It is sometimes difficult to identify the horizon when one is flying. Clouds, fog, mountains, or wooded areas may obstruct the view. The artificial horizon serves as a substitute for the actual horizon.

The artificial horizon is simply a bubble level. It is constructed by trapping air in a liquid-filled tube. Light from a small bulb passes through the bubble and produces a light ring. This ring is seen against a darker background. The light ring is projected into the field of vision along with the heavenly body which is being sighted. The field of view is also transversed by a set of crosshairs. These serve as an aid in orienting the instrument. When the circle of light is centered in the crosshairs, the sextant is plumb and level with the line of the horizon.

The periscopic sextant is made for use in high-speed, pressurized aircraft. Its accuracy is not impaired when used under other conditions.

The sextant is used to measure celestial altitudes. The mount and the sextant are both permanent parts of the aircraft.

The sextant system consists of two main items. These are the mount and the sextant. An understanding of these components and their functions is necessary. We will describe these components, starting with the mount.

Exercises (B12):

1. State what part of the sextant is used to align it with the horizon.

2. What is the sextant used to measure?

B13. State the purpose of the mount locking pins and shutter drain and specify the electrical power requirements.

The Mount. The sextant mount (see fig. 5-10) is attached to the top of the aircraft fuselage. The sextant is held in the mount by two locking pins. One of these pins is usually black and is labled TO RETRACT SEXTANT - PULL. The other (TO INSERT, REMOVE -PULL) is silver.

Just as they are labeled, you use the silver (TO INSERT, REMOVE - PULL) pin to insert the sextant into the mount or remove it from the mount. You use the black (TO RETRACT SEXTANT - PULL) pin to retract the sextant from the extended (viewing) position. This pin is spring loaded and will automatically snap into place when the sextant is extended.

When installed in the mount, the sextant may be rotated through 360° in azimuth. A friction-type clamping lever controls the ease of sextant rotation. It is capable of locking the instrument at any position. The position of which it is locked is read on the azimuth scale (in ½° increments) by means of the lubber line. The azimuth counter gives a readout of this position in degrees and tenths of a degree. The azimuth scale moves when the azimuth crank is turned. The azimuth counter also moves and is synchronized with the scale. By turning the crank and reading the azimuth counter, you can set the scale to within one-tenth of a degree. The coupling between the azimuth ring and the azimuth counter is secured by two Bristol set screws. They may be loosened to adjust synchronization between the azimuth ring and counter. Another larger screw is used to adjust for endplay in the drive. It should not be tampered with.

The mount is equipped with gimbals which permit the sextant to be used and kept level throughout aircraft altitude variations up to 15° in pitch and roll.

Electrical power of 28 volts DC is supplied to the mount from the aircraft. It is supplied through a cable connection on the side of the mount. A switch on the side of the mount controls the power to both the mount and the sextant. The mount has one lamp which illuminates the azimuth counter. Another electric cable is connected from the mount to the sextant.

Shutter Assembly. The large lever above the mount controls the shutter. It is normally kept closed to maintain pressure in the aircraft. The shutter is opened just

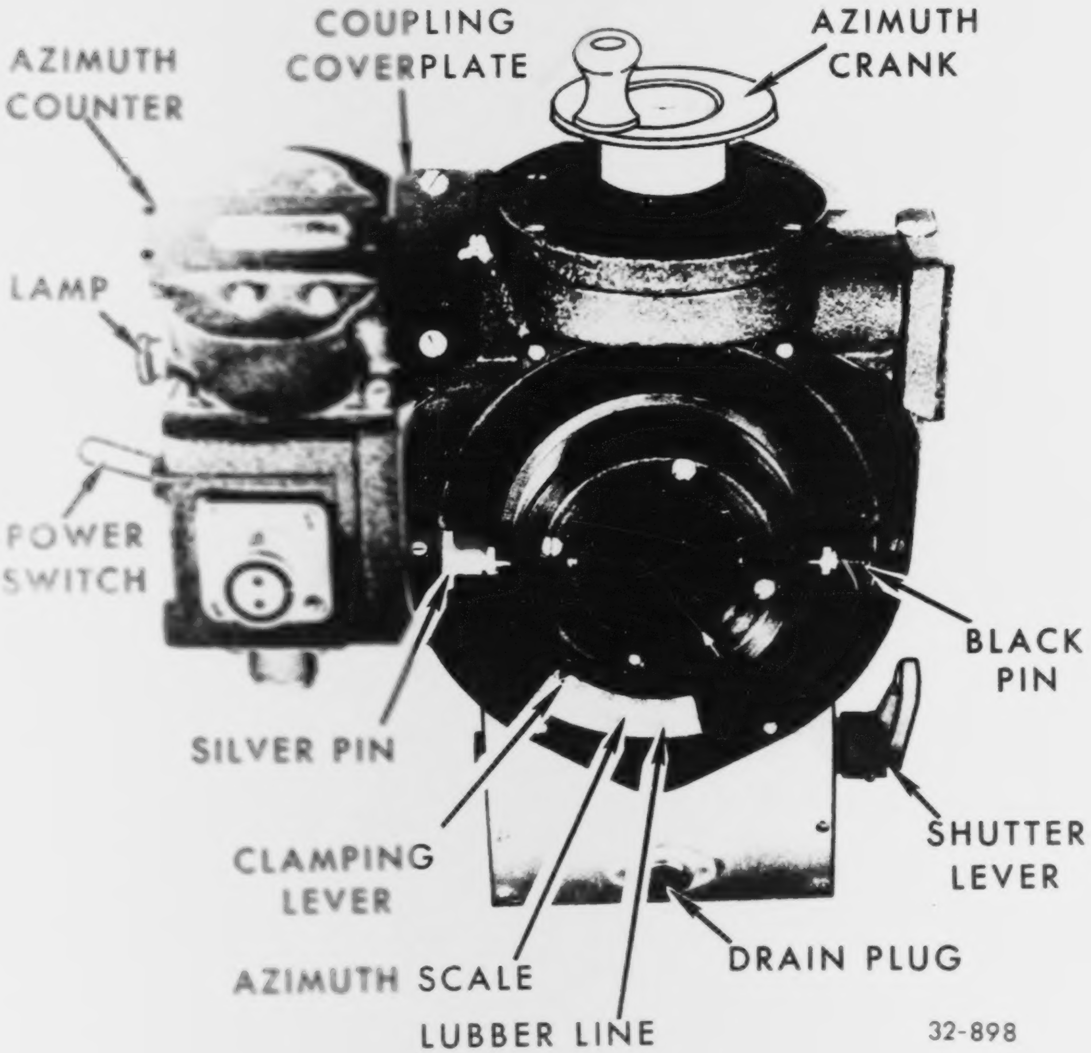
COUPLING COVERPLATE
AZIMUTH CRANK
AZIMUTH COUNTER
LAMP
POWER SWITCH
BLACK PIN
SILVER PIN
SHUTTER LEVER
CLAMPING LEVER
DRAIN PLUG
AZIMUTH SCALE
LUBBER LINE
32-898

Figure 5-10. Sextant mount.

before the sextant is to be used. This allows the sextant to be extended for observing a celestial body. The sextant reseals the pressurized cockpit as it enters the shutter opening. A water trap and drain plug are provided in the shutter assembly so that condensed moisture can be removed. Binding and jamming due to freezing of the shutter and lever mechanism can thus be prevented.

Exercises (B13):

1. State the purpose of the mount locking pins.

2. What is the sextant mount electrical power requirement?

3. State the purpose of the shutter drain.

B14. List the five subassemblies of the sextant and state the purpose of the averager assembly.

Sextant Subassemblies. The sextant is divided into five subassemblies. These are:

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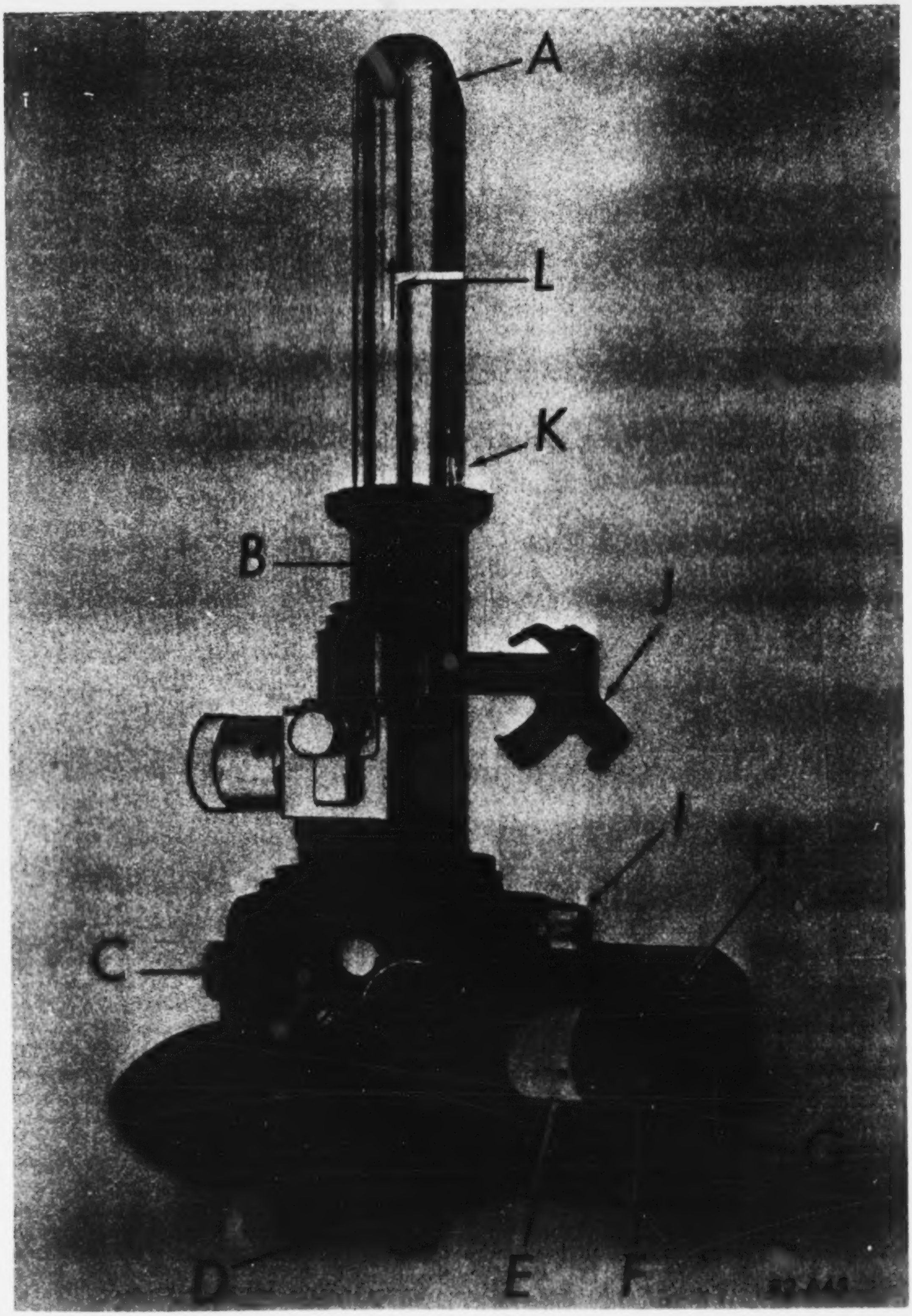


A. Objective window
B. Telescope tube
C. Rheostat knob
D. Bubble prism mount assembly
E. Altitude control knob
F. Altitude control dial
G. Averager assembly
H. Index discs
I. Light
J. Watch clip
K. Locating key
L. Alignment arrow

Figure 5-11. Periscopic sextant (front view).

(1) The averager.
(2) The telescope tube.
(3) The sextant body.
(4) The bubble unit.
(5) The eyepiece assembly.

To better understand just how the sextant works, we will study these subassemblies on an individual basis. Let's start with the averager.

The averager. The averager is the most complex of the subassemblies. This device is attached to the side of the sextant. It is designed to interpret the action of a moving ball across a rotating disc. As a result it will accurately compute an average angle for any time interval up to 2 minutes. An automatic device causes a shutter to block the optical path. This indicates that the observation is complete. The shutter is closed by the various subassemblies of the averager. Figure 5-11, item G, shows the averager assembly.

Exercises (B14):

1. List the five subassemblies of the sextant.

2. State the purpose of the averager assembly.

B15. State the range of the index prism, state what is used to drive the index prism and altitude counter dial, and describe the purpose of the bubble prism mount assembly.

The telescope tube. The telescope tube (B) in figure 5-11 is the next unit of the sextant to be considered. This tube is sealed to prevent condensation on the objective window (A) when the tube is extended into the cold air. A small container of silica gel can be seen through the objective window. This provides a warning of excessive moisture inside the tube. When the air is dry, the silica gel is blue in color. As the gel absorbs moisture, it turns pink in color. The pink indicates the need for replacement of the gel.

The index prism is in the top of the sextant tube. It permits observation at any angle between minus 10° and plus 92°. This is relative to the use of the bubble horizon. The index prism is rotated by the altitude control knob (E). A guide pin, locating key (K), and an alignment arrow (L) are provided on the tube. These are used for ease and safety in installing the sextant into the mount. A watch clip (J) is attached to the lower part of the tube.

The sextant body. Some models have a silica gel indicator located on the left side of the body. The altitude knob is used to move the index prism. The position of the index prism is indicated in degrees and minutes by the altitude counter (altitude control dial, item F). The altitude counter dial is driven mechanically by the altitude control knob. Above the altitude control knob is the light (I) which illuminates the altitude counter dial, the index discs (H), and the watch clip. This light and the light on the bubble unit are operated by a switch on the junction box of the mount.

On the front of the sextant, above the eyepiece, is a rheostat knob (C). This is used to control the brightness of the bubble light. A filter lens knob is on the left side of the body. It is used to select any one of the eight positions of the filter lens assembly. If the sun is viewed, you will not be able to see the bubble unless a filter is inserted. The circular piece on the bottom of the body is the bubble prism mount assembly (D). This is used to focus the bubble image. Notice the AN plug on the body. There is an electrical cable provided to connect this point to an AN plug on the mount.

Exercises (B15):

1. What is the range of the index prism?

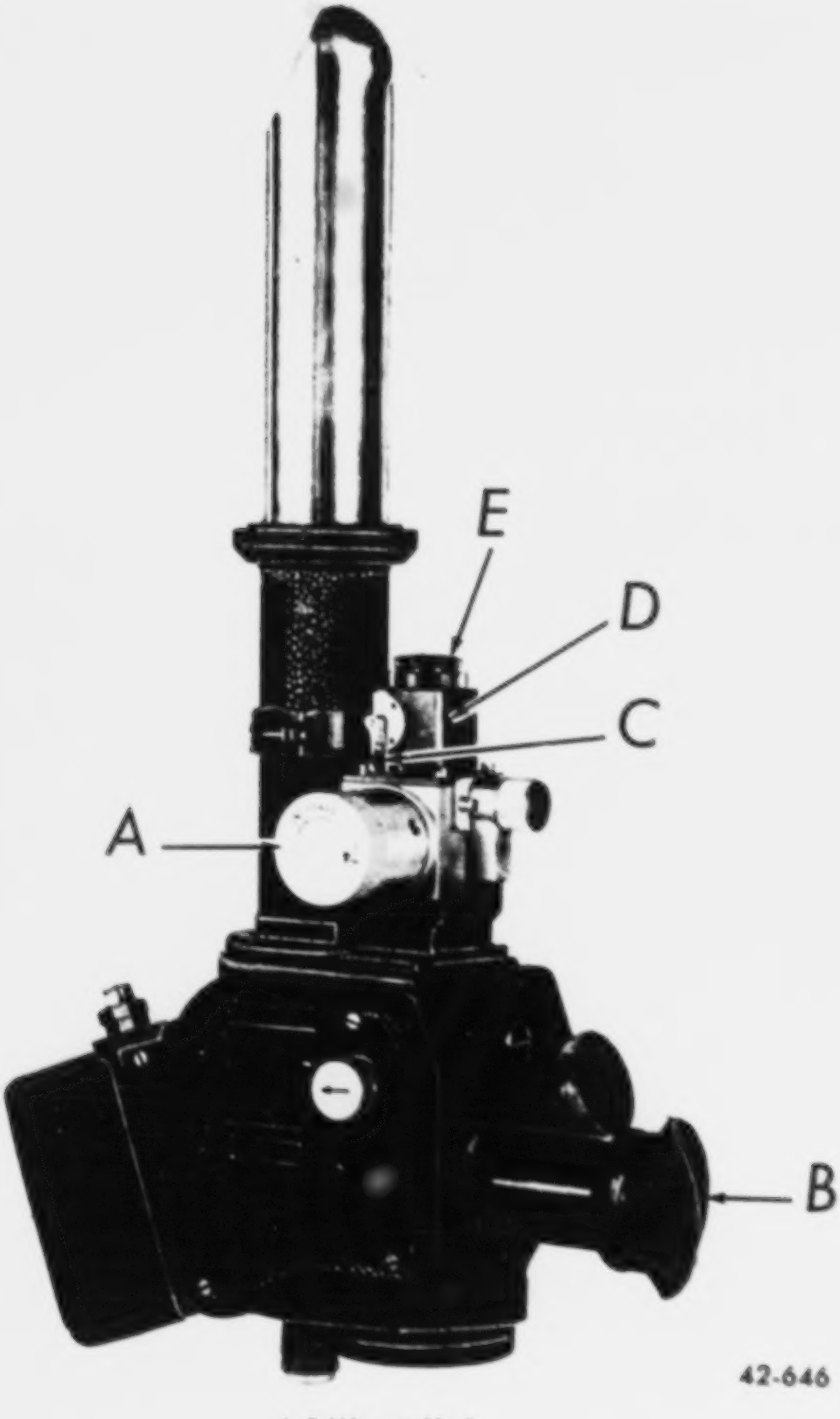
2. State what is used to drive the index prism and altitude counter dial.

3. What is the purpose of the bubble prism mount assembly?

B16. Give characteristics of the bubble unit and the eyepiece assembly.

The bubble unit. The bubble unit is shown in figure 5-12. It is used to keep the sextant level when readings are taken. On the top of the unit is a true heading projection lens assembly (E). During the day, sunlight enters here to light up the bubble background. This arrangement of the lens enables you to see the true heading scale on the bottom of the sextant mount at the same time that you view the celestial body. The diffuser lever (C) is installed on the light control shutter housing (D). This controls the amount of sunlight entering the bubble unit.

For night use, the bubble is illuminated by a 3-volt lamp. The brightness of the lamp is regulated by the rheostat located on the body. The bubble control knob (A) is on the left side of the bubble unit. It is used to form and control the size of the bubble. After an adjustment is completed, the control knob should be slowly positioned to the full INCREASE BUBBLE position.



A. Bubble control knob
B. Eyepiece assembly
C. Diffuser lever
D. Shutter housing
E. Projection lens assembly

Figure 5-12. Periscopic sextant (left side view).

The eyepiece assembly. The eyepiece assembly (B) is attached to the body of the sextant with six screws. It can be focused to plus or minus 2 diopters. A rubber eye guard is fitted onto the end of the assembly. We have now covered the major assemblies of the sextant. Now let's discuss how this instrument operates.

Exercises (B16):

1. What controls the amount of sunlight entering the bubble unit?

2. After adjustment of the bubble size, where should the bubble control be positioned?

3. How much can the eyepiece be adjusted?

B17. Explain the operation of the sextant.

Operation of the Sextant. Let's discuss how we obtain the altitude of a celestial body, even though this is not the avionic instrument specialist's job. The sextant is first placed in the mount. The arrows on the tube and the mount are aligned. While the sextant is held steady, the silver pin is pulled out. The pin section is rotated fully counterclockwise. The pin falls into place when it is released. This locks the sextant in a retracted position. Move the shutter lever of the mount to the point of shutter opening. Push up on the sextant until the black pin drops home.

Connect the electrical cables and form the bubble. To form the bubble, look into the eyepiece and tilt the sextant. Tilt it until the notch in the bubble cell appears at the TWO O'CLOCK position. Turn the bubble adjustment knob in the INCREASE BUBBLE direction. The bubble will appear in the notch. Adjust it until its size is one and one-half to two times the size of the sun, as seen through the eyepiece. When the bubble is the right size, return the sextant to the vertical position. Move the bubble control to the full increase position. The bubble control knob has little effect on the bubble size when the sextant is vertical. A bellows in the control knob acts as a pressure and temperature compensator when the control knob is in the full increase position.

When the bubble is too small, the bubble control knob is returned to the DECREASE position. Again tilt the sextant to the TWO O'CLOCK position, so the bubble is in the notch. Rotate the knob toward the increase position until the bubble is the correct size.

This method of bubble size adjustment is repeated as many times as necessary to increase bubble size. To decrease the bubble, reverse the process. Tilt the sextant to the TWO O'CLOCK position. Move the knob toward DECREASE until the bubble is the desired size. Hold the sextant in the vertical position and return bubble control to the full INCREASE position. Once this is done, depress the rewind lever at the back of the averager. Estimate the altitude of the celestial body. Set this figure on the altitude counter by rotating the altitude control knob. The azimuth angle is also estimated. Set this figure in the azimuth counter by turning the azimuth crank. Bring the celestial body into collimation (line of sight) by turning the sextant and adjusting the altitude control knob. Collimation involves adjustment until the body is seen in the center of the light ring formed by the bubble. Observe the time on the master watch and press the averager button.

The observation has now begun. A ticking sound indicates that the averager is in operation. Keep the body in collimation by operating the altitude control knob. To discontinue the shot, press the averager button a second time. The minimum time for a shot is 30 seconds (15 seconds on the half-time dial). This stops the observation. Otherwise the mechanism will discontinue its operation automatically after 2 minutes. The shutter will close to indicate that the shot has been completed.

Viewed through the eyepiece, true heading is read from the azimuth scale. The vertical crosshair serves as the pointer. Now we must get an average of our shots for this one observation.

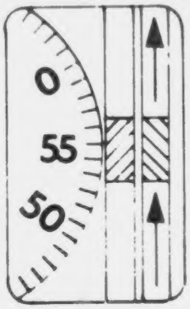


Figure 5-13. Indexing discs and half-time dial.

In figure 5-13, notice the half-time dial next to the disc. It is driven by the clock-drive mechanism. This dial is calibrated in half time. It indicates half of the elapsed time of the observation. Add this reading to the time at the beginning of the observation, or subtract it from the time of the completion. The result is the mean time for the observation. To the right of the half-time dial are the index discs (see fig. 5-13). One disc will have arrows. These arrows indicate the direction the index must be moved to return it to the starting point.

Obtain the angular altitude of the body as follows. Rotate the altitude control knob until the two index markers on the discs coincide. Figure 5-13 shows the discs in proper alignment. When this has been completed, the altitude counter is read in terms of degrees and minutes.

When the true azimuth is set into the azimuth counter, the true heading can be read on the azimuth scale. Use the vertical crosshair as a reference. When the body is in collimation, read the azimuth scale.

This procedure is the navigator's job. We have described the actual use of the sextant to provide you with an insight into optical navigation. If you are interested in these calculations, consult a text on navigation. Of greater concern to you now is the subject of maintenance. We will turn to that subject next.

Exercises (B17):

1. How long will the averager remain in operation?

2. What indicates that an observation has been completed?

3. Identify what scale true heading is read from.

4. State the purpose of the arrows on the index disc.

B18. Identify the errors corrected with the collimator and specify the errors that can be adjusted for in the pivot assembly.

Maintenance. The extent of maintenance depends on the organization to which you are assigned. It includes the following: Replacing light bulbs, cleaning outside glass surfaces, checking mount alignment, checking sextant collimation, and changing desiccant.

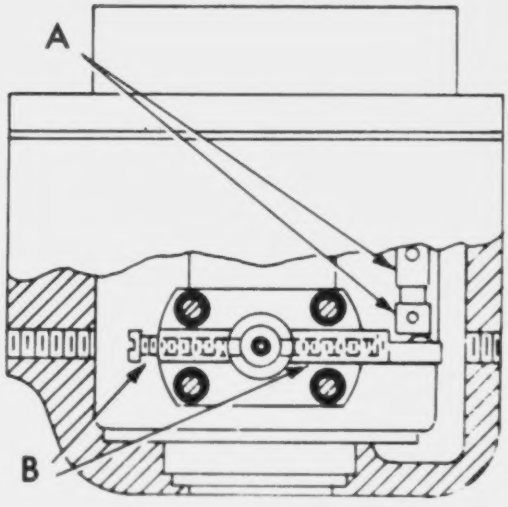
Your organization may or may not permit internal adjustments of instruments. We cannot overemphasize referring you to technical orders on these matters. Use TO procedures.

The index and inherent error of the sextant are corrected using a collimator. The collimator projects parallel light rays at a given angle with respect to the horizontal.

Collimation. Collimation of sextants is done with a gang-type collimator. This device may have three or four light tubes. These tubes are located at 0°, 45°, and 90°. If the fourth tube is used, it is located at – 10°. Install the sextant in the collimator, making sure that it is level and plumb in the mount. Procedures for this are outlined in the applicable TO. Using the altitude control knob, align the crosshairs of the sextant with the crosshairs of the 0° tube of the collimator. Note the reading of the altitude counter (dial F, fig. 5-11). Follow the same steps for the 45° and 90° light tubes. At each reading, the dial should indicate the same angle as that of the light tube.

If an error exists, there are three possible corrections that can be made. The most commonly found error, readings that are all positive or negative, can be corrected at the altitude counter. Sight the sextant on the 45° tube. Carefully remove the counter. Loosen the setscrews on the coupling and rotate the counter shaft until the counter reads exactly 45°. Retighten the setscrews and install the counter on the sextant. Recheck the sextant on the 0° and 90° tubes.

If range errors such as 0° = 00:05°, 45° = 45:00°, 90° = 89:55° or curve errors such as 0° = 00:01°, 45° = 45:05°, 90° = 90:10° exist, internal adjustments must be made. This is done by removing the cover plate that houses the filter control knob. These adjustments are shown in figure 5-14. Part A is a range adjustment nut. This controls the length of the rod which operates the index prism. Corrections for range error are made at this nut. Screw B affects the curve error. This screw controls the fulcrum point of the leverl pivot arm. Repositioning the fulcrum point varies the amount of travel which the lever transfers to the index prism push rod. Make sure, if you must tighten one of the screws on the lever, that you first loosen the screw on the opposite side. After all adjustments have been made and the sextant is in collimation, replace the cover plate. Now we have a serviceable sextant to work with. Let's take it out to the aircraft and check the amount.



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A. Range adjustment nut B. Curve error screw

Figure 5-14. Pivot assembly.

Exercises (B18):

1. Identify the errors that are corrected with a collimator.

2. What errors are corrected by making adjustments of the adjustment screws under the cover that houses the filter control knob?

B19. Specify the accuracy required of the sextant and the adjustments made to align the sextant on the aircraft.

Azimuth scale/counter agreement. With the sextant in the shooting position, sight on the lubber line of the amount. The azimuth scale is read against the lubber line (small black traingle). It should agree with the azimuth counter plus or minus one tenth of a degree. To correct an agreement error, follow the procedures given in the applicable technical order.

Mount alignment. With the bubble centered, align the vertical crosshair of the sextant with the aircraft vertical stabilizer. The reading on the azimuth scale should agree with the reading given in the TO. If an error exists, you must make the following adjustments. First loosen the locknut on the sextant projection lens. Rotate the lens assembly until the azimuth reading is correct. Retighten the locknut. If the mount cannot be brought into alignment by adjusting the projection lens, it must be physically aligned. Loosen the four datum screws located at the top of the mount. Grasp the mount carefully in both hands and turn it until it comes into alignment. Retighten the datum screws.

The navigator or boom operator usually checks these alignments before making any flights. All of the adjustments are your responsibility. You may think that the sextant system is complicated and hard to understand and work with. This feeling will disappear as you learn the system. Study the sextant technical orders and those of the applicable aircraft. If you have any questions about a sextant, ask your supervisors. The aircraft navigators are usually glad to help and are probably the people best informed on the sextant and its operation.

Exercises (B19):

1. State how accurately the sextant should agree with the azimuth scale.

2. What is the first adjustment you make to align the sextant on the aircraft?

Instrument Systems Test Equipment

WE HAVE COME a long way since the time that we could use two wet fingers to determine if the juice (voltage) was available or not. Precision instruments require precision test equipment. Precision test equipment requires users, (your) knowledgeable in its care and use.

Like the cost of everything else, the cost of test equipment is skyrocketing with inflation. If you have a thorough knowledge of test equipment and are skillful in its use, you can not only maintain instruments and instrument systems in excellent condition, but you may also save many Air Force dollars by extending the useful life of this valuable equipment through proper care and maintenance.

The test equipment covered in this chapter may not be the exact type that you have in your particular section. We have chosen a basic representation of each category of general test equipment. Even if you have the type of equipment discussed in this chapter, the model or series may be different. Remember, therefore, to always consult the appropriate technical order before using or working on any test equipment.

6-1. Calibration, Modification, and Repair

All instrument test equipment must be maintained so that it is usable at all times. If it isn't done by you, the user, it will be done by another Air Force agency.

B20. Specify procedures used to verify calibration of precision measuring equipment.

Precision Measurement Equipment (PME). Practically every type of aircraft system has special equipment for checking the condition, adjustment, or calibration of specific units in the system. This special equipment is called precision measurement equipment or test equipment. Test equipment can come in many forms. It may be as simple a device as a "gauge" used to check the pressure in the hydraulic system, or as complex as an oscilloscope. This test equipment will be a valuable maintenance aid because it enables you to insure the serviceability and reliability of the units it is designed to test.

Before using any test equipment, check it to insure that it is all there, and that it is in serviceable condition. There is probably nothing more discouraging than lugging a piece of test equipment from the shop to the flight line, then finding that all pieces that you need to perform your test aren't with it. After using the equipment, store it properly. Return all parts to their proper storage container so that the next time the equipment is needed it will be there.

Test equipment requires verification (checking for accuracy) and calibration (adjusting for accuracy) at scheduled intervals. If the unit must be checked, the check will be performed by the precision measurement equipment laboratory (PMEL). When the check (or calibration) is completed, an AFTO Form 108, PME Certification Label, will be affixed in a conspicuous place upon the item.

AFTO Form 394, PME Certification Label, is used when the equipment is too small to accommodate an AFTO Form 108. The labels will tell you when the next calibration is due. Always check the label for the calibration due date before using the equipment.

If it shows that the check is due or past due, do not use the equipment until it has been checked by PMEL for accuracy. These calibration requirements are given in the 33 category (test equipment) TOs. Each test equipment TO gives the manufacturer's recommended calibration procedures and the calibration time requirements applicable to the equipment.

On complex PME, such as test stands, one certification label will suffice for all items that are an integral part of it. An item is considered an integral part if it must be calibrated as a part of the stand. Equipment normally removed from the stand for calibration is not an integral part, and will have individual certification labels.

One other form you will come in contact with is the AFTO Form 255, Notice Certification Void When Seal is Broken. It is placed on the equipment in such a manner that any attempt to repair or adjust the equipment will result in breaking the seal. If the seal is broken, you have no idea whether the equipment is calibrated correctly. The equipment must then be rechecked or calibrated if necessary.

Some units of test equipment do not require scheduled checks. An AFTO Form 256, No Calibration Required, (NCR) sticker is used on this equipment. This does not imply that they may be handled carelessly or abused. You have a responsibility to properly care for all equipment issued by the Air Force, whether it is assigned to you, or your shop.

One rule that should be followed is, whenever an item of equipment leaves your shop, you should have a signed receipt for it. AF Form 1297, Temporary Issue Receipt, is used to issue an item of equipment for short periods of time. Let's say an engine mechanic needs to borrow a special wrench to remove a pump from an aircraft. Have this person sign for it on a temporary hand receipt, which then holds him or her responsible for the equipment until it is returned.

Exercises (B20):

1. Who is to perform the check on the precision measuring instrument?

2. Describe what you should do before you use test equipment.

3. What is the difference between verification and calibration?

4. Where would you find information concerning calibration requirements for test equipment?

5. Which form would you use to loan a special tool to another mechanic on a temporary basis?

6. What is the purpose of AFTO Form 255?

B21. Describe the authorization and the procedures followed for PMEL and shop calibration.

Calibration of Test Equipment. There are two types of calibration on test equipment. One is done by the precision measurement equipment laboratory. The other is done in the shop. To find out which equipment you are authorized to calibrate, check your PMEL monthly schedule and TO 33K1-100. What is the difference between the two calibrations? Actually, very little, though some items require special calibration equipment and specially trained people to use it. How often should you calibrate your test equipment? There is no common time interval for all your equipment. The best way to handle this is to consult the 33K-100 TO. It lists each item and its calibration time requirements.

PMEL calibration. As you already know, calibration is done at a PMEL by specially trained technicians. PMEL normally informs you when your equipment is due for calibration by sending you copies of the monthly schedule. This is a machine (IBM) list of your test equipment, giving the following: (1) item name, (2) serial number, (3) model number, (4) date last calibrated, and (5) date presently due. There are other items of information in the report, but the items above are the important ones as far as your shop goes. Whenever you receive your shop's copies of the schedule, check the equipment against the list to make sure each entry is valid. If there are any errors, make the necessary corrections and forward one copy of the corrected report back to PMEL. Tag the equipment to be calibrated and make it available for PMEL pickup. This tagging and PMEL preparation should be finished at least 48 hours before the due date, because PMEL requires the equipment to be in its shop 24 hours before the "due calibration" date. Keep in mind that any item whose calibration is overdue is considered unsafe for use. Don't allow yourself to be caught using unsafe equipment.

Shop calibration. Like PMEL calibration, it is also scheduled. The big difference is that you do not receive a PMEL monthly schedule to tell you when calibration is due. You should keep a schedule in your shop listing all your test equipment and telling who calibrates it and when. Just as PMEL does with the equipment they calibrate, put stickers on shop calibration items showing the last calibration date and the due date. The sticker on shop calibrated equipment should also show who calibrated the equipment. Through the daily inspections and checks of your schedule, you can schedule your calibrations so they won't interfere with your normal maintenance activities. If you have only two identical test sets, don't try to calibrate both at the same time. If you do, you may find yourself in a jam, with aircraft to repair and no test equipment to use. When you repair any of your test equipment and the repair requires calibration, make sure you update the calibration sticker and your schedule. Remember, the better the calibration of your test equipment, the better your aircraft system calibrations will turn out. Specific calibration procedures are given in the applicable TO for each piece of equipment. A system half-calibrated is a malfunction in the making.

Exercises (B21):

1. What TO identifies the activity authorized to calibrate test equipment?

2. Describe the primary difference between PMEL calibration and shop calibration.

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3. How do you notify PMEL if you discover an error in the PMEL monthly schedule?

B22. Give the reasons for, and limitations in, modifying and repairing test equipment.

As with the aircraft systems you are tasked to maintain, you must also maintain all assigned test equipment. This includes repairing damages and equipment malfunctions; however, there are restrictions as to what you may do.

Equipment Modification. We all know that, when a new aircraft is built, it must be modified a few times to make it function better or to meet new mission requirements. Whenever some item in your system is updated in the aircraft, its test equipment must also be updated to meet the changes in maintenance requirements. Making the change in the test equipment is usually your responsibility. The modification directive comes from the equipment manufacturer or the depot and can consist of anything from a switch change to a complete overhauling. The degree of the modification depends on the change in the aircraft system.

The modification directive for your test equipment comes as a TCTO with a certain amount of time allowed to complete the work. Sometimes, if you have two test sets, the TCTO will tell you to modify only one of them. It will also tell you that only a part of the aircraft on which the test set is used is being modified, and that the modified set is to be used on this part. Naturally, the unmodified set will continue to be used on the unmodified aircraft. The TCTO will also tell you to identify the modified test set, usually by stamping a single digit dash number to the part number on the nameplate. Custody and other records have to be changed to reflect the change in test set identification. Check the modification TO to see what must be done and the number of manhours involved. Check the included parts list to see if you have all that you need to complete the modification. When you complete this check, assign the people to start the modification. If you have more than one test set, modify only one set at a time. This prevents having both sets down when the tester is needed. After the modification is complete, bring your inventory listings and schedules up-to-date. If the modification has changed the PMEL calibrated equipment, change your copy of the PMEL monthly schedule. In addition, see that PMEL is informed of the change.

This brief discussion on test equipment may be somewhat different from your local procedures, but the basic requirements are the same.

Equipment Repairs. The owning work center supervisor (your shop chief) is responsible for organizational maintenance on precision measurement equipment. Maintenance for PME designated in TO 33K-1-100 as common, NCR/COM, or PMEL supported includes cleaning, replacing, or repairing those parts that do not affect calibration or certification of the equipment. No maintenance should be attempted on this type of equipment in your shop that would require internal adjustment or that might affect its calibration or certification. The maintenance that you may do includes (but is not limited to):

a. Replacing defective knobs on controls.

b. Cleaning air filters.

c. Cleaning, painting, and maintaining test equipment and their shipping cases.

d. Replacing hasps, latches, and handles.

e. Replacing unsafe power cords (in accordance with TO 33-1-32).

f. Replacing defective detachable leads (except those which affect calibration and must be calibrated with the tester such as fuel quantity test leads).

g. Maintaining other connecting cables and accessories which do not require calibration.

h. Insuring proper fuse protection and replacing missing fuse caps.

i. Replacing pilot lights and lenses.

j. Replacing or charging batteries and energy cells. Periodically check batteries for leakage and corrosion caused by battery leakage.

There is no set limit to the extent of maintenance which may be done at your level on PME. However, it must be done utilizing available manpower, skills, authorized equipment and facilities strictly following prescribed TO procedures. You will find that these factors prevent you from doing much test equipment maintenance. If any maintenance is done which may affect the calibration or certification of the equipment, it must be calibrated on certified before it is used.

If you do not have the skills, equipment, tools, or tech data needed to repair a tester, *do not* attempt the repairs. Send it to PMEL, depot, or another maintenance shop where it can be repaired properly.

Exercises (B22):

1. Why is test equipment sometimes modified?

2. If two identical items of test equipment require modification, should both be modified at the same time? Explain your answer.

6-2. Torque Wrenches and Tensiometers

We covered the use of torque wrenches in a previous volume. In this section, we will explain the calibration of torque wrenches and tensiometers.

B23. State torque wrench calibration requirements and procedures.

Torque Wrenches. Because of the need for special testers to test and verify torque wrench readings, the responsibility for calibrating them was assigned to one shop, the avionics instrument shop. Now let's see what is involved in this testing and calibration.

Verification. To verify torque wrenches, they should be checked on an authorized torque wrench tester which is assigned to your shop and has been calibrated by PMEL. The tester must be level. Set the torque wrench handle to the lowest setting and attach it to the tester. Before taking any test readings, you should actuate the torque wrench through a few release cycles. This allows the internal mechanism to spread a thin film of lubricant throughout the working parts of the wrench. After you have done this, take the test readings at the following test points: (1) 20 percent, (2) 40 percent, (3) 60 percent, (4) 80 percent, and (5) the highest setting (full load range capacity). For example, a torque wrench with a range of 150 inch-pounds is tested at 30 (20%), 60 (40%), 90 (60%), 120 (80%), and 150 (full). A torque wrench with a range of 1,600 inch-pounds is verified at 400, 800, 1,200 and 1,600 inch-pounds. At each of the four test points, pull the torque wrench handle slowly and smoothly while watching the tester for the proper release point. Do this three times for each test point. All readings must be within the specified tolerances for these test points given in the TO. By using the average of the readings at each test point, you can obtain a precise indication of the releasing capabilities of the torque wrench.

Calibration. If a torque wrench is out of tolerance according to the applicable technical order, it needs to be readjusted (calibrated). Manufacturers equip their torque wrenches with different methods of adjustment. Before adjusting a torque wrench, you must read and follow the step-by-step TO procedures for your wrench. Some wrenches have an Allen-head screw adjustment in the tube between the handle and the drive assembly. You adjust some by adding or removing spacing washers from the adjustment bolt on the end of adjustment handle grip. You adjust others by loosening and turning the handle to the proper setting and then retightening the handle. These adjustments affect every setting on the wrench by the same amount.

The range adjustment is also made on the torque wrench tester. There is usually a small cap screw on the side of the wrench body filled with a fusible alloy that must be removed. Under it, you will find another Allen-head screw. Adjusting this screw affects range of the wrench. If the low-range and high-range readings are within tolerance, the mid range readings are also normally within tolerance. After you have adjusted the torque wrench properly, again check the test points from the highest to the lowest settings for verification. Remember, after you have used any torque wrench, always set it at the lowest setting to remove excessive spring tension in the wrench.

The adjustments on torque wrenches are usually sealed with a fusible allow to keep them from being tampered with or accidentally moved out of adjustment. Do not use solder to reseal the torque wrench adjustment. The flux in the solder and the high heat required to melt the solder can damage the wrench. You can remove the fusible alloy with boiling water or by other approved heating methods. The alloy melts at approximately 70° Celsius, which is equal to 158° Fahrenheit. This is considered a low temperature. To seal the torque wrench adjustment, use a low heat producing element, such as a low wattage soldering iron, to melt the fusible alloy into the Allen-head screw holes. Then smooth the fusible alloy with a file or sandpaper until it is flush with the top of the metal.

Marking. After the wrench has been calibrated and/or tested and determined accurate, the day, month, and year for reverification must be shown on the wrench. You can use a white strip of paper to show the date the wrench is to be tested again. Secure the label with transparent tape so that the date is visible.

Calibration control. You initiate calibration control. After you have taken all the necessary steps for testing and/or adjusting, you must prepare an AFTO Form 349, Maintenance Data Collection Record. This form accounts for your maintenance time and provides information for updating the Maintenance Data Collection Equipment Inventory Report 2. This report lists all test equipment that requires calibration, and contains several sections. Since the torque wrenches are Category II equipment, they are listed in the Category II equipment section. Like any machine run listing, most of it is in code. Some types of information it contains are: (1) owning work center number, (2) type of wrench, (3) serial number, (4) calibration dates, (5) calibrating work center number, and (6) the wrench ID number, if assigned. With the machine run in your area, annotate it with the new due date for cross reference to the new list which is published the following month.

Exercises (B23):

1. What procedure insures that the internal parts of the torque wrench are coated with a thin film of lubrication?

2. List the points where you should test a torque wrench.

3. What settings are affected when the handle is adjusted?

4. What must the specialist remove from the torque wrench before making a range adjustment? Where is it?

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5. State two factors that can damage the torque wrench if solder is used to seal the Allen-head screw holes.

6. Name the report that contains information used for torque wrench control.

B24. Identify the parts of a tensiometer and specify procedures used to determine cable tension.

Tensiometer. To determine the amount of tension on a cable, a tensiometer is used. When properly maintained, a tensiometer is 98 percent accurate. Cable tension is determined by measuring the amount of force needed to make an offset in the cable between two hardened steel blocks, called anvils. A plunger is pressed against the cable to form the offset. Several manufacturers make a variety of tensiometers for the Air Force. Each type is designed for different kinds of cable, cable sizes, and cable tensions. In the information that follows, we discuss the C-8 (USAF type No.). An understanding of this type should enable you to use and calibrate the other types of tensiometers that are available.

Figure 6-1 shows a representative type of C-8 tensiometer. Observing the figure, notice that the tensiometer consists of anvils and a plunger to clamp on the cable for which tension is being measured. This particular tensiometer is designed to measure tensions from 10 to 200 pounds. Also, observe that a cable size indicator is installed to measure the size of the cable for which tension is being measured. The purpose of the handle on the tensiometer is to clamp the cable in place or to release the cable during tension measurements. Tension readings are taken on the indicator dial that can be preset (zeroed) for the cable size that is being measured. Now read the steps outlined below that show how the tensiometer is operated when you are checking cable tension.

(1) Determine cable size being measured.

(a) Lock the tensiometer handle to the closed position by means of the handle lock.

(b) Rotate the cable size indicator counterclockwise to the stop position.

(c) Clamp the tensiometer on the cable by releasing the handle slowly (depress handle to release from the locked position).

(d) Close and lock the handle.

(e) Read the cable diameter on the cable size indicator.

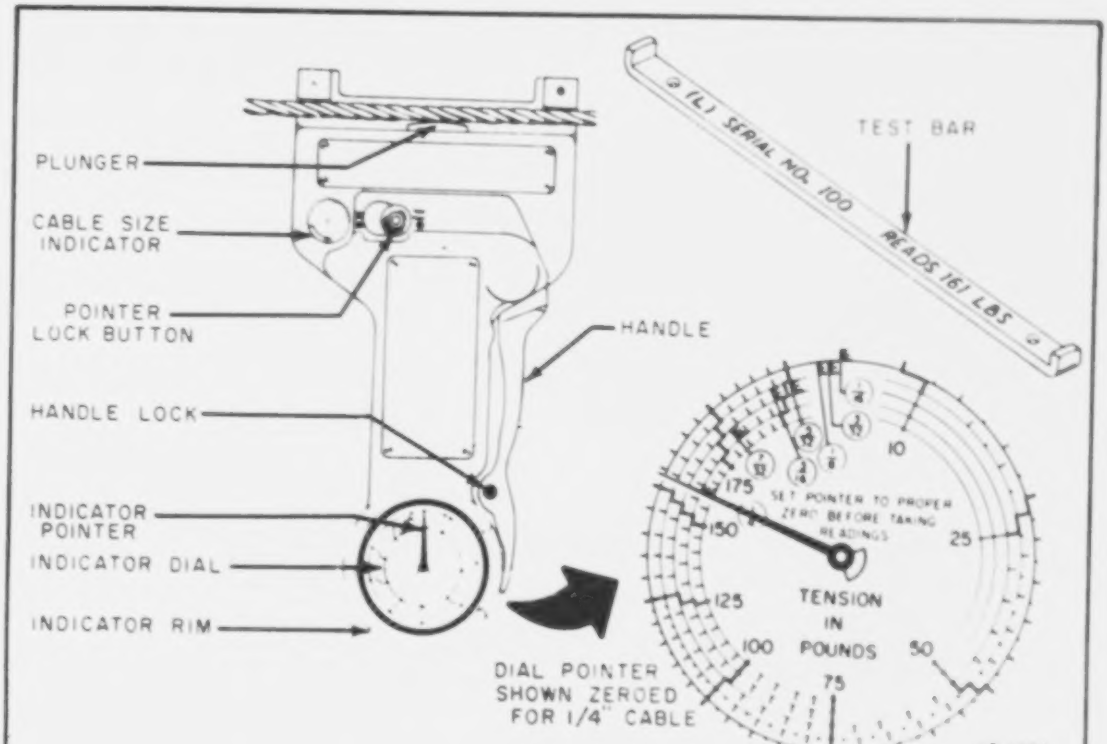
PLUNGER
CABLE SIZE INDICATOR
POINTER LOCK BUTTON
HANDLE LOCK
INDICATOR POINTER
INDICATOR DIAL
INDICATOR RIM
HANDLE
(L) SERIAL NO. 100 READS 161 LBS
TEST BAR
SET POINTER TO PROPER ZERO BEFORE TAKING READINGS
10
25
50
75
100
125
150
175
TENSION IN POUNDS
DIAL POINTER SHOWN ZEROED FOR 1/4" CABLE
42-1531

Figure 6-1. C-8 Tensiometer.

(2) Zero the indicator pointer for the cable size being measured by rotating the indicator rim so that the pointer is zeroed over the cable size being measured (see lower right detail in fig. 6-1).

(3) Measure cable tension.

(a) Clamp the tensiometer on the cable by releasing the handle slowly.

(b) Read cable tension on the correct dial for the particular cable size being measured. (Observing lower right detail, notice that circled cable size has a line pointing to dial to be read.)

NOTE: If the indicator dial is not visible during a measurement, slide the pointer lock button to "ON" before removing the tensiometer from the cable. This will lock the pointer in its position so you can turn the tensiometer around to read it.

If a tensiometer is suspected of being incorrect, you can check it with the use of the test bar shown in the upper right-hand corner of the illustration. The indicator rim must be zeroed for 1/16-inch cable, and the test bar inserted in the tensiometer with the end marked "L" to the left and with the flanges pointing up. The average of three or more tension values obtained should be within 2 percent of the value indicated on the test bar if the tensiometer is accurate.

Only the type C-8 and C-9 tensiometers are equipped with test bars which must be used daily to verify the continued accuracy of the tensionmeters. Other types must be checked on a tester in the instrument shop. The tester has several sizes of cables which may be stretched to precise tensions as indicated on the tester dial. Check each tensiometer at the center of each different size cable for which it is used and at the test points specified in the appropriate TO. Update the next DATE DUE CALIBRATION in the same manner as for torque wrenches.

Exercises (B24):

1. What is the purpose of the cable size indicator?

2. Where is the cable placed on the tensiometer?

3. What is the purpose of the handle?

4. How could you lock in the cable tension indicator before removing the tensiometer from the cable?

5. In what direction would the cable size indicator be rotated before the tensiometer is clamped on the cable?

6. What happens when the tensiometer handle is released when measuring a cable?

7. How can you check the tensiometer for accuracy?

8. Specify how the tensiometer is zeroed.

6-3. Multimeters

The multimeter or volt-ohm-milliammeter (VOM) is a multirange, multifunction instrument. It is used to measure AC and DC voltage, DC current, and resistance. You used the AN/PSM-6 type at the technical school for your 3-level training. As a quick review, we will discuss the type AN/PSM-37. However, keep in mind that you should always follow the appropriate technical order when using any multimeter.

B25. State the purpose of the AN/PSM-37 and of selected controls, and describe voltage, current, and resistance measurement procedures.

Multimeter, AN/PSM-37. The multimeter is a precision general-purpose test instrument that combines the functions of an AC and DC voltmeter (with both 20,000 ohms-per-volt and 1000 ohms-per-volt meter sensitivities), an ammeter, and an ohmmeter.

Switches and controls. The FUNCTION switch (see fig. 6-2) is located at the lower left of the multimeter panel and provides the means of setting the instrument for the particular electrical characteristic to be measured.

The RANGE switch is located at the lower right of the panel. Once the FUNCTION switch has been set, use the range switch to select the correct instrument range. As with the AN/PSM-6, the value being measured should be read near the center of the lowest readable scale.

The POLARITY switch is located centrally on the right side of the panel but is not marked as such. It turns the multimeter on and off and selects the type of measurement to be made, DC +, DC −, and AC. The + and − polarity indicates the polarity applied to the red jack when the meter reads upscale on DC measurements, and it indicates the output polarity of the red jack when making ohms measurements.

The OHMS ADJUST control is located centrally on the left side of the panel and is used only to set full-scale deflection with the test leads shorted together prior to making resistance measurements. This control adjusts for variations due to battery condition, temperature, and range and function settings.

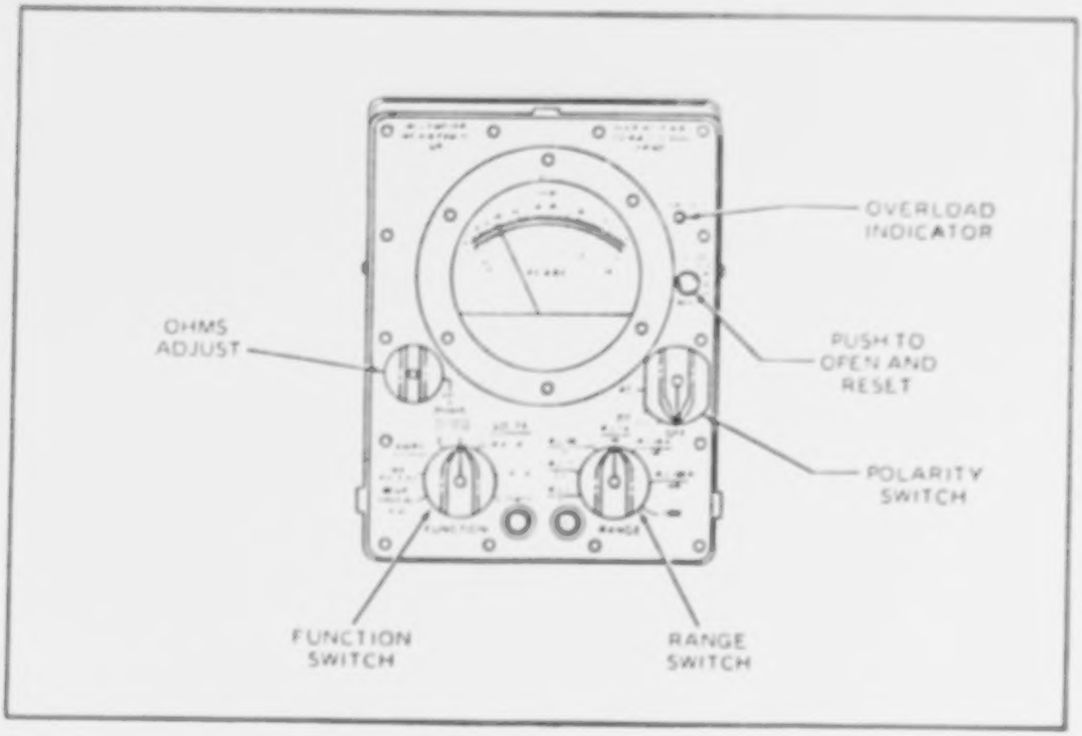

Figure 6-2. AN-PSM37 Multimeter.

The PUSH TO OPEN AND RESET control is located adjacent to the meter on the right side of the panel. The overload circuit breaker is manually opened when this button is depressed, permitting changes in range and function settings without disconnecting the test leads from the circuit. Depressing this button also resets the overload breaker if it has been actuated. Prior to making any measurements, check that the overload protector is not tripped, as indicated by the OVERLOAD indicator. If an overload is indicated, or when in doubt, reset the meter by depressing and releasing the PUSH TO OPEN AND RESET button.

Voltage measurements. AC and DC voltages may be measured directly on the PSM-37 in the range of 0 to 1000 volts at input impedances of 1000 ohms/volt, 20,000 ohms/volt, or at a fixed 10 megohms. These impedance functions are marked on the panel under the VOLTS caption around the FUNCTION switch. Measurement of small signals up to 100 millivolts at 1000 ohms (10,000 ohms/volts) is available under the SPECIAL function marked on the panel under the AMPS caption. To measure voltages in the range of 0 to 1000 volts, the procedure is as follows:

(1) Set the FUNCTION switch to 20k Ω /V, 1k Ω /V, or 10 meg Ω as desired. The 10 meg Ω function is inherently protected against overload and is recommended for initial measurements.

(2) Set the RANGE switch to the desired full range.

CAUTION: Whenever taking an unknown voltage measurement, always set the RANGE switch to the highest range and decrease until the proper range is reached.

(3) Turn the POLARITY switch to DC +, DC −, or AC as desired.

(4) Connect the test leads to the meter jacks; the red lead to the red (+) jack.

(5) Connect the test lead tips in parallel with the circuit being measured, with the black lead to ground or lower voltage point, if known. If the meter reads the reverse on DC measurements, change the POLARITY switch to the opposite polarity.

WARNING: The lack of a meter reading does NOT mean the circuit is safe, since dangerous levels of voltages of other polarities may be present. The overload circuit may activate due to the presence of undetected voltage and must be checked before concluding no voltage is present.

(6) If a voltage below 100 millivolts is indicated, the FUNCTION switch may be set to SPECIAL and the measurements taken. The position of the RANGE switch does not affect the full scale value of the SPECIAL FUNCTION. The 10 meg Ω function employs a blocking capacitor when set on AC polarity and permits the reading of low AC signals present on higher level DC voltages.

High-voltage or high-impedance AC and DC voltage measurements can be obtained through the use of the test probe which permits AC and DC voltage measurements up to 5000 volts at an input impedance of 1000 megohms.

Current measurements. AC and DC currents (including pulsed DC) from 0 to 1 ampere may be measured directly on the multimeter, and currents up to 10 amperes may be measured with the use of the multirange instrument shunt which is stored in the meter cover. The procedure is as follows:

(1) Set the FUNCTION switch to MA/PULSE MA.

(2) For measurements up to 1 ampere, set the RANGE switch as desired.

(3) Set the POLARITY switch to DC+, DC−, or AC as desired.

(4) Plug the test leads into the meter jacks. Connect the other end of the leads *in series with the circuit* under test while the power is off. Turn on the power and read the meter.

(5) For measurements above 1 ampere, connect the test lead tips to pin jacks in the shunt MX-9127/PSM-37. Connect the circuit under test to the appropriate load circuit binding posts. Set the RANGE switch to 2.5 or 10 to correspond with the shunt section used.

(6) Turn on the power and read the meter. For a 2.5-ampere shunt section, the meter is set for 2.5 and reads 2.5 amperes full scale. Use of the 10-ampere shunt results in a full-scale value of 10 amperes.

(D) If a current below 100 microamperes is indicated, the FUNCTION switch may be set to SPECIAL and a full-scale value of 100 microamperes obtained.

Resistance measurements. To measure resistance from 0 to 100 megohms, the procedure is as follows:

(1) Set the FUNCTION switch to OHMS LP or OHMS STD, depending on whether 100 millivolts or 850 millivolts output is desired. OHMS LP is generally used to measure in-circuit resistance where semiconductor junctions will block out the effect of other components. OHMS STD is best to check semiconductors for forward and reverse conduction and to minimize the effects of thermal, chemical, or leakage voltage.

(2) Set the POLARITY switch to DC+.

(3) Set the RANGE switch at the proper multiplier so that the resistance measure falls in the broader portion of the green OHMS scale on the meter. The OHMS STD junction is disabled on the RX1 range to prevent delivery of excessive current into the test items.

(4) Plug the test leads into the meter jacks, short circuit the free ends of the test leads, and adjust OHMS ADJ until full-scale deflection (0 ohms) is obtained.

(5) Clip the test leads across the item to be measured. Read the resistance on the OHMS scale and multiply the reading by the range setting.

(6) If resistance in the opposite direction is also desired, change the POLARITY switch to DC− and read. The polarity of the red jack matches the setting of the POLARITY switch. An internal regulator circuit precludes resetting zero for routine range-to-range, function-to-function, or battery discharge effects. This permits rapid in-circuit measurements at LP and STD, forward and reverse polarity, without disconnecting the leads during the test to rezero. Different forward and reverse readings will be obtained on a known passive device only if outside power is passing through the device. The overload is active at all times on OHMS functions to indicate the presence of unexpected voltage when making resistance measurements.

Storage. Upon completion of measurements, turn the POLARITY switch to the OFF position. The internal amplifiers draw battery current whenever the POLARITY switch is not off. When fresh, the batteries will operate the multimeter for at least 5000 hours at midscale on the OHMS functions and for several thousand hours on all other functions. The multimeter must be off before the cover will fit properly. This is due to a mechanical interference interlock designed into the POLARITY switch knob to prevent improper storage of the meter.

Exercises (B25):

1. What is the purpose of the AN/PSM-37?

2. What is the purpose of the RANGE switch?

3. What does the OHMS ADJUST control compensate for?

4. What input impedance is recommended for initial voltage measurements?

5. To measure voltage, how are the test leads connected in the circuit under test?

6. If you wish to measure a 50-millivolt signal, what position of the FUNCTION switch should you use?

7. What position of the FUNCTION switch is used when measuring current?

8. When measuring current, how is the meter connected in the circuit under test?

9. Which ohms position of the FUNCTION switch is best to measure the forward and reverse conduction of semiconductors?

10. Why are the test leads shorted prior to using the PSM-37 as an ohmmeter?

11. How can resistance in the opposite direction be measured without removing the test leads?

6-4. Vacuum Tube Voltmeter (VTVM)

A vacuum tube voltmeter (VTVM) has the advantage of having very high input impedance when compared to a great many other multimeters. The VTVM described in this section has an input impedance of 2 megohms, as Compared to a PSM-6, which has an input impedance for AC of 1 kilohm per volt. This high input impedance decreases circuit loading and increases meter accuracy.

B26. State the uses of the electronic multimeter ME-6D/U and explain its operation.

Electronic Multimeter ME-6D/U. The electronic multimeter ME-6D/U (fig. 6-3) is a highly sensitive instrument for accurately measuring AC voltages by the vacuum tube voltmeter principle.

The multimeter covers the voltage range from 500 microvolts RMS to 500 volts RMS within the frequency limits from 15 Hertz to 250 kilohertz. The meter scale has two calibrations: the upper scale showing AC voltage from 0.5 to 5 (with slight extensions below and above this range for overalp), and the lower scale indicating decivels over the range from -5 to + 17 based on 0 db = 0.001 watt in 600 ohms.

An auxiliary purpose of the multimeter is to serve as a flat high-gain wideband amplifier. Its frequency response approximates that of the voltmeter, from a nominal 15 Hertz to 250 kilohertz. Maximum voltage gain of about 4500 can be achieved. An essentially distortionless waveshape is obtainable up to at least 23 volts AC output.

Power requirements. The multimeter operates from 117 volts ± 10 percent, 50 – to 400-Hertz, single-phase AC.

Logarithmic scale. The Model ME-6D/U is a logarithmic type AC vacuum tube voltmeter. Figure 6-4 illustrates the logarithmic scale of the ME-6D/U. Notice that the marks are not evenly spaced. This non-

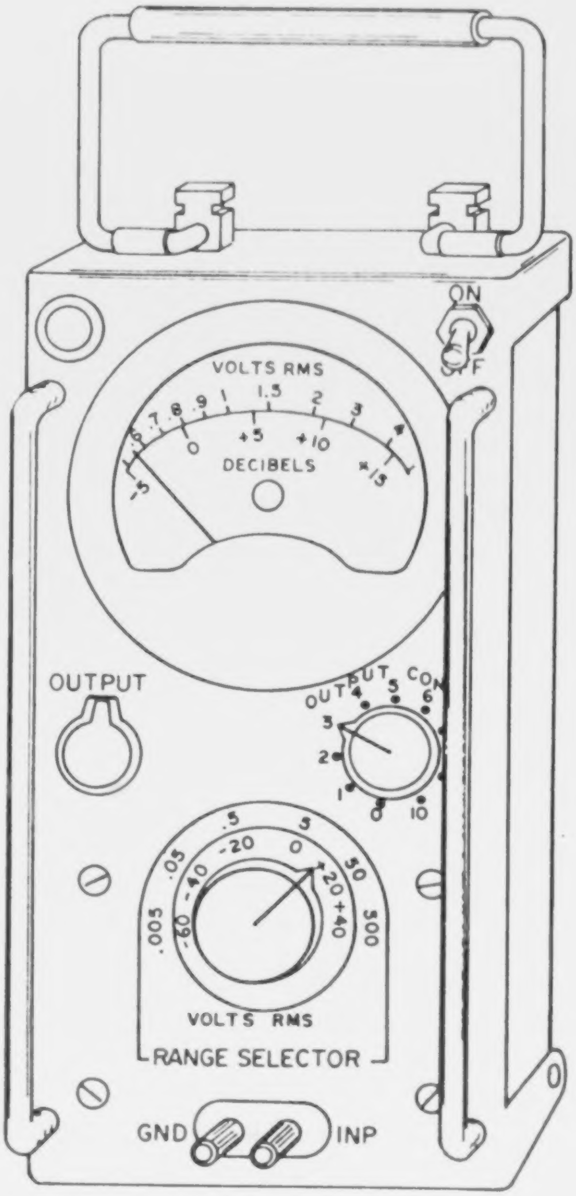

Figure 6-3. ME-6 Voltmeter.

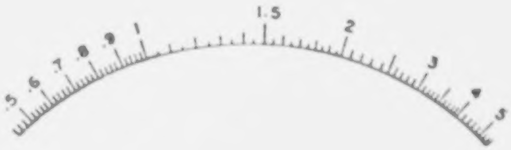

Figure 6-4. Logarithmic scale used on ME-6 Voltmeter.

linearity has the advantage of spreading out the lower end of the scale. Readings can, therefore, be more accurate than is possible with a linear scale.

Operation. Before beginning to use the ME-6D/U, there are three important precautions to observe. First, do not measure line voltage or any two phases of three-phase power. Second, observe the correct polarity when making test lead connections. Third, when using an isolation adapter plug, set the meter on an insulating pad and touch only the plastic range selector knob and the insulated test leads. An isolation adapter (often called a ground buster) is an adapter that is inserted between the meter power plug and the power source. It removes the case ground from the meter and provides a floating ground, which is required in some troubleshooting and alignment techniques.

Operate the ME-6D/U as follows:

(1) Insure the range selector is set to 500.

(2) Connect the test leads to the meter.

(3) Connect the power cord to a 115-VAC, 50– to 400-Hertz power source.

(4) Turn the power switch on and allow 2 minutes for warmup.

(5) Connect the leads of the circuit to be tested (GND lead first).

(6) Turn the range selector down scale until meter registers between .5 and 5 on the scale markings.

(7) Return the range selector to 500 when completed.

(8) Disconnect the leads from the circuit being tested (INP lead first).

(9) Disconnect from the power source.

Exercises (B26):

1. What are the two uses of the ME-6D/U?

2. What are the three precautions to observe before using the ME-6D/U?

3. Briefly explain the operation of the ME-6D/U.

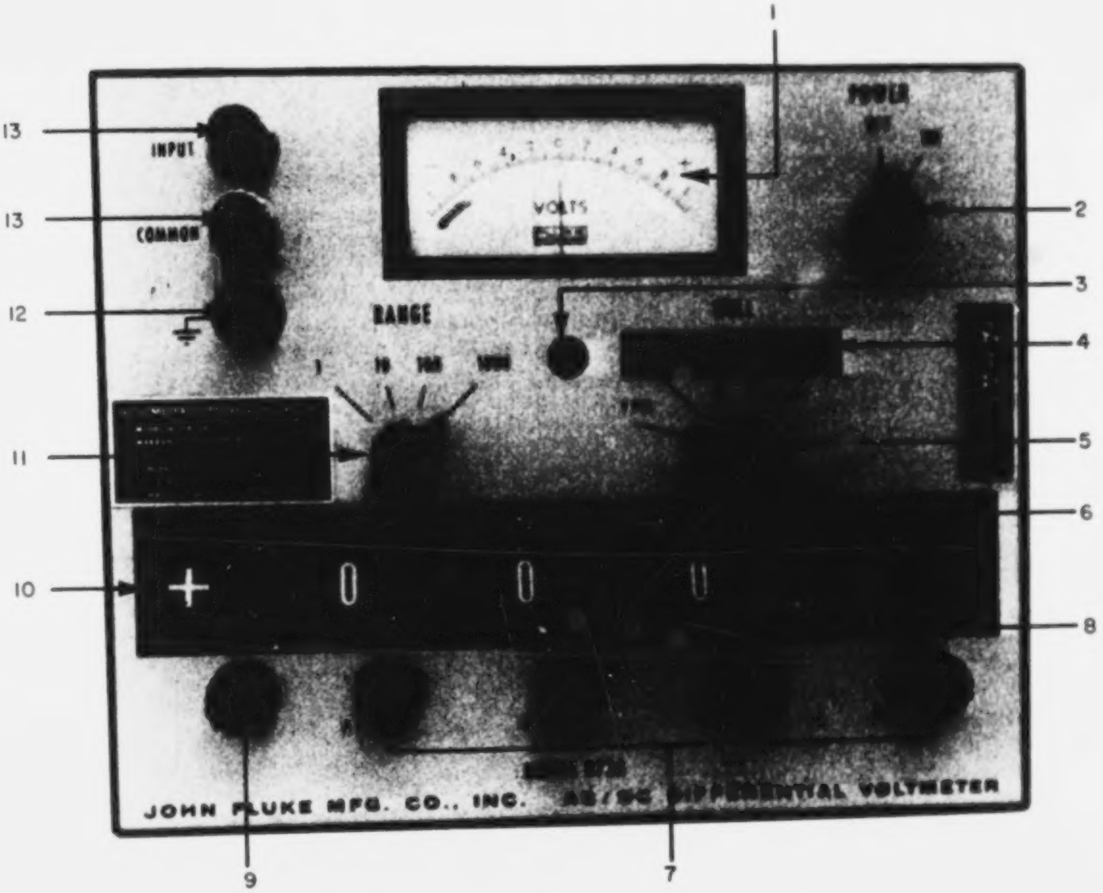

Figure 6-5. Model 873A Differential Voltmeter.

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TABLE 6-1

CONTROLS, TERMINALS, AND INDICATORS ON THE 873A DIFFERENTIAL VOLTMETER

1. Meter. Indicates approximate voltage when 873A is in TVM (voltmeter use) mode.

2. Power Switch. Applies AC line voltage to the primary circuit of the power transformer.

3. Mechanical Zero Control. Sets meter to zero mechanically.

4. Null Dial. Shows null ranges as range control is changed.

5. Null Switch. Selects specific null range to be used.

6. Readout Windows. Provide an in-line readout of the amount of internal reference voltage necessary to null the unknown voltage.

7. Readout Dials. Used to null the unknown voltage and set readout window values.

8. Decimal Windows. Serve as decimal points for the voltage readout windows. Decimal points change as range knob is changed.

9. AC-DC Polarity Switch. Selects the AC, +DC, or -DC mode of operation.

10. AC-DC Readout Window. Provides a readout to let the operator know the position of the AC-DC Polarity Switch.

11. Range Switch. Selects desired voltage range. Full scale voltage ranges of 1, 10, 100, and 1000 volts are available.

12. Chassis Ground Terminal. Provided for grounding purposes.

13. Input Terminals. Provided for connecting AC or DC voltage to be measured.

6-5. Differential voltmeter

Sometimes, more accurate measurement of critical voltages is necessary. When you need a precision voltmeter to do certain troubleshooting, a differential voltmeter may fill your need.

B27. State the uses of the Model 873A Differential Voltmeter and the function of selected controls, terminals, and indicators on the 873A.

The 873A Differential Voltmeter. The 873A Differential Voltmeter is capable of being used as (1) a conventional voltmeter for rapid determination of AC and DC voltages from 0 to 1100 volts to within 3 percent of range setting, (2) a differential voltmeter for precise measurement of AC and DC voltages from 0 to 1100 volts, and (3) a megohmmeter for measurement of resistance from 10 megohms to 100,000 megohms with a typical accuracy of 5 percent.

When used as a differential voltmeter, the 873A operates on the potentiometer principle. An unknown voltage is measured by comparing it to a known, adjustable DC voltage with the aid of a null detector and, for AC measurements, an AC to DC converter.

Function of controls, terminals, and indicators. The location and functional description of the external controls, terminals, and indicators on the 873A AC/DC Differential Voltmeter are given in figure 6-5 and table 6-1.

Setup operation. The following procedure prepares the Model 873A for operation.

(1) Mechanically zero the meter with the adjustment screw on the front panel. If the instrument has been operating, it must be shut off for at least 3 minutes, with the meter terminals shorted, prior to this adjustment.

(2) Connect the power plug to a 115-volt, 50- to 400-Hz AC power outlet.

(3) Set switches on 873A as follows:

RANGE	1000
NULL	TVM
POLARITY	+ (positive)
All voltage readout dials	Zero
POWER	ON

Exercises (B27):

1. What are the uses of the 873A?

2. What is the function of the following controls, terminals, or indicators?
   a. Null dial.

   b. Decimal window.

   c. AC-DC readout window.

3. What is the position of the following switches after the setup operation is performed?

   a. RANGE.

   b. NULL.

   c. POLARITY.

   d. All voltage readout dials.

   e. POWER.

B28. Explain the operation of the Model 873A as a differential voltmeter and as a megohmmeter.

Operating as a DC differential voltmeter. The procedure to operate the 873A as a DC differential voltmeter is as follows:

(1) Peform the setup operation.

(2) Connect the unknown voltage between INPUT and COMMON post. If one side is grounded, always connect it to the COMMON post.

(3) Turn the RANGE switch to lowest range that will permit on-scale meter deflection, and note approximate value of unknown voltage.

(4) If the meter deflects to the left, the polarity of the unknown voltage is negative. Turn POLARITY switch to the negative position. The meter will deflect to the right.

(5) Noting position of decimal point, set the four voltage readout dials to the approximate voltage determined in set (3). For example, if the approximate voltage was 35 volts, the decimal point will be between the B and C readout dials. Therefore, set dial A to 3 and dial B to 5.

(6) Set the NULL switch from TVM to the first null position for the range being used, and adjust the readout dials for zero meter deflection.

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TABLE 6-2
TVM RANGES

	FULL-SCALE DEFLECTION (VOLTS)	POLARITY SWITCH POSITION	RANGE SWITCH POSITION	NULL SWITCH POSITION	VOLTAGE READOUT DIAL POSITIONS
DC:					
	1000-0-1000	+	1000	TVM	No effect
	100-0-100	+	100	TVM	No effect
	10-0-10	+	10	TVM	No effect
	1-0-1	+	1	TVM	No effect
	.1-0-.1	+	1	.1	All zero
	.01-0-.01	+	1	.01	All zero
	.001-0-.001	+	1	.001	All zero
AC:					
	0-1000	AC	1000	TVM	No effect
	0-100	AC	100	TVM	No effect
	0-10	AC	10	TVM	No effect
	0-1	AC	1	TVM	No effect
	0-.1	AC	1	.1	All zero
	0-.01	AC	1	.01	All zero
	0-.001	AC	1	.001	All zero

(7) Adjust the readout dials for zero meter deflection in successively more sensitive null ranges. When the meter needle deflects to the right, the magnitude of the voltage under measurement is greater than the voltage set on the readout dials. When deflection is to the left, the voltage under measurement is less than the voltage set on the readout dials.

(8) When the meter is at null on the most sensitive null range, the unknown voltage equals the value set on the four readout dials.

Operating as an AC differential voltmeter. The procedure to operate the 873A as an AC differential voltmeter is as follows:

(1) Perform setup operation.

(2) Set the POLARITY switch to AC.

(3) Connect the unknown AC voltage between INPUT and COMMON posts. If one side is grounded, always connect it to the COMMON post.

(4) Set the RANGE switch to the lowest range that will allow an on-scale reading and note the approximate value of the unknown voltage as indicated on meter scale.

(5) Noting the position of the decimal point, set four voltage readout dials to the approximate voltage determined in step (4). For example, if the voltage is approximately 35 volts, the decimal point will alread be between the B and C voltage readout dials. Therefore, set dial A to 3 and set dial B to 5.

(6) Set the NULL switch to successively more sensitive null ranges and adjust the voltage readout dials for zero meter deflection in each null position. When the meter needle indicates to the right, the magnitude of voltage being measured is greater than the voltage set on the voltage readout dials. When the indication is to the left, voltage is less than that set on the readout dials.

(7) Read the unknown voltage directly from the four voltage readout dials.

Operation as a conventional voltmeter. If it is desired to use the instrument as a conventional 3-percent voltmeter only, additional ranges can be made available by converting the NULL range to conventional voltmeter ranges. This is made possible by setting the voltage readout dials to zero, and setting the RANGE switch to 1 volt. Proceed as follows:

(1) Perform the setup operation.

(2) Refer to table 6-2, and select the full scale voltage deflection desired. If the approximate value of voltage to be measured is unknown, select the 1000-volt range initially.

(3) Set the RANGE switch, NULL switch, and voltage dials as indicated in table 6-2 for the range selected.

(4) Connect the voltage to be measured between INPUT and COMMON posts. If one side is grounded, always connect it to the COMMON post. Deflection to the right indicates that the unknown DC voltage is of

TABLE 6-3

RESISTANCE MEASUREMENTS AT FULL SCALE DEFLECTION

RANGE OF UNKNOWN RESISTANCE	NULL SWITCH POSITION	UNKNOWN RESISTANCE IN MEGOHMS AT FULL-SCALE (-1.0) METER DEFLECTION
10 megohms to 100 megohms	1	Multiply amount set on voltage readout dials by 10 and subtract 10.
90 megohms to 1090 megohms	0.1	Multiply amount set on voltage readout dials by 100 and subtract 10.
1000 megohms to 11,000 megohms	0.001	Multiply amount set on voltage readout dials by 1000.

positive polarity. An unknown AC voltage will always cause deflection to the right.

Operation as a megohmmeter. The 873A series voltmeter may be used as a megohmmeter for rapid measurements of high resistance from 10 megohms to 100,000 megohms with a typical accuracy of 5 percent. The following equation may be used to compute the resistance in megohms of an unknown resistance connected to the input binding posts when the RANGE switch is set to 10.

$$R_X = R_i \frac{E\ 1}{E_m}$$

Where:

R^x is the unknown resistance in megohms.
E is the voltage indicated by the voltage readout dials.
E_m is the voltage indicated on the meter.
R_i is the input resistance of the TVM circuit in megohms.
R_i is equal to 10 for the 1 and 0.1 null positions, and 1 for the 0.01 and 0.001 null positions.

A convenient way of measuring leakage resistance between 10 megohms and 11,000 megohms is to adjust the voltage readout dials so that the meter indicates full scale (–1.0). The unknown resistance is then easily calculated from the readout dial setting. Proceed as follows:

(1) Perform the setup operation.
(2) Set the RANGE switch to 10.
(3) Set the NULL switch to 1.
(4) Connect the unknown resistance between INPUT post and COMMON post. Use short insulated leads to prevent measuring the leakage resistance between the leads.
(5) Adjust the voltage readout dials for full-scal meter deflection (–1.0). If full-scale deflection canno be obtained with the NULL switch set to 1, set th NULL switch to 0.1 or 0.001.
(6) Determine the value of the unknown resistanc according to table 6-3.

Exercises (B28):

1. Briefly explain how to operate the 873A when using it as a differential voltmeter.

2. Briefly explain how to operate the 873A when using it as a conventional voltmeter.

3. Briefly explain how to operate the 873A when used as an ohmmeter to measure high resistance.

6-6. Model 3440A Digital Voltmeter

The Model 3440A Digital Voltmeter displays positive or negative DC voltages to four significant figures from 0.001 volt to 1000.0 volts. A plug-in unit must be installed in the front panel compartment of the Model 3440A for measurements. Six plug-in units are presently available for use with the Model 3440A.

Inputs to the digital voltmeter can be sampled at rates ranging from 5 samples per second to 1 sample per 5 seconds. When the voltmeter is used with the appropriate plug-in unit, range selection can be remotely controlled. The Model 3440A is designed to provide output information to a digital recorder.

B29. Describe the Model 3440A Digital Voltmeter and state the purpose of selected plug-ins.

Instrument Description. The Model 3440A Digital Voltmeter is designed to measure DC voltages from 1 millivolt to 1,000 volts with an accuracy of ±0.05 percent. With the appropriate plug-in unit installed, the 3440A will measure AC volts, DC volts, DC amps, or ohms. Polarity is automatically indicated. The last completed measurement is displayed until a new measurement cycle is completed. This display storage feature prevents flickering of the readout during the measurement cycle. Measurement sampling time is controlled by the front panel SAMPLE RATE control. Selection of range is controlled by the RANGE switch on the plug-in unit. Remote control of sample rate and range selection is available with some of the plug-in units. A digital recorder output is also available through use of an external digital recorder. Mode of operation is also controlled by plug-in controls.

Plug-In Units. A plug-in unit is necessary for operation and is an integral part of the voltmeter circuit. Available plug-ins are listed below. Table 6-4 is a comparison chart of the various plug-ins:

a. The Model 3441A Range Selector provides manual selection of 10-, 100-, and 1000-volt ranges.

b. The Model 3442A Automatic Range Selector provides manual, automatic, and remote selection of 10-, 100-, and 1000-volt range.

c. The Model 3443A High Gain/Auto Range Unit provides manual, automatic, and remote selection of 100- and 1000-millivolt and 10-, 100-, and 1000-volt ranges.

d. The Model 3444A DC Multi-Function Unit provides a manual ranging DC voltmeter, DC milliammeter, and ohmmeter. Five ranges are provided for each function. (Full-scale voltage ranges from 100 millivolts to 1000 volts, full-scale current ranges from 100 microamperes to 1000 milliamperes, and full-scale resistance ranges from 1000 ohms to 10 megohms.)

e. The Model 3445A AC/DC Range Unit provides manual, automatic, and remote selection of 10-, 100-, and 1000-volt ranges for both AC and DC voltages.

f. The Model 3446A AC/DC Remote Unit provides AC and DC measurements of 10, 100, and 1000 volts full scale. Both range and function may be selected either manually or remotely.

Once the plug-in unit has been installed in the Model 3440A, the instrument is ready for operation. Connect the power cable supplied with the instrument and check for proper power source and power cable requirements.

Power Requirements. The Model 3440A can be operated from a 115- or 230-volt, 50- to 1000-Hz AC source. Primary power requirements are set by the rear panel LINE VOLTAGE switch. Before plugging the Model 3440A into the power source, check that the designation on the two-position LINE SELECTOR switch matches the line voltage of your power source. The AC line fuse should be a 0.6-ampere, slow-blow type for both 115- and 230-volt modes of operation.

Overrange Operation. The Model 3440A can be operated with input signals 5 percent overrange with no loss in accuracy when giving five-digit resolution at these points. The first significant figure will not be seen under these circumstances. For example, if the 10-volt range is selected and the input voltage is 10.500 volts, the front panel reading will be 0.500 volt and the OVERRANGE light will be lighted.

Exercises (B29):

1. State the purpose of the Model 3440A Digital Voltmeter.

2. Using table 6-4, give the function (volts, amps, etc.) of the following plug-in units.
   a. 3441A.

   b. 3444A.

   c. 3446A.

3. What are the power requirements for the Model 3440A?

4. With a range setting of 10, what happens when 10.5 VDC is applied to the 3440A?

6-7. The Tektronix 453 Oscilloscope

One of the most versatile pieces of test equipment that you will use is the oscilloscope. Some of its many uses are visual waveshape displays, frequency measurement, voltage measurement, pulse width measurement, and phase relationship to other input signals. We are going to limit our discussion to the two most common uses—voltage and frequency measurement.

Although some older model tube-type oscilloscopes (Example: Tektronix 545A) are still in the Air Force inventory, we will limit our discussion to the newer

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TABLE 6-4

PLUG-IN FUNCTION CHART

PLUG-IN	AC VOLTS 10V TO 1000V	DC VOLTS 10V TO 1000V	DC VOLTS 100 MV TO 1000V	DC AMPS	OHMS	REMOTE FUNCTION	AUTO RANGING	FLOATING INPUT	PRINTER OUTPUT	REMOTE RANGING	REMOTE TRIGGERING
3441A	*	X						X	X		X
3442A	*	X					X	X	X	X	X
3443A	*		X				X	X	X	X	X
3444A	*		X	X	X			X	X		X
3445A	X	X					X	X	X	X	X
3446A	X	X				X		X	X	X	X

*TRUE RMS VOLTAGE MEASUREMENTS: 1MV to 300 VOLTS (10 CPS TO 10 MC) USING THE 3400A.

transistor-type oscilloscope, the Tektronix 453; however, keep in mind that you should always follow the appropriate technical order when using any oscilloscope.

To effectively use the Type 453, you must know the operation and capabilities of the instrument. This section describes the operation of the front-, side-, and rear-panel controls and connectors, gives first time and general operating information, and lists some basic applications for this instrument.

The front cover furnished with the type 453 provides a dust-tight seal around the front panel. Use the cover to protect the front panel when storing or transporting the instrument.

The handle of the Type 453 can be positioned for carrying or as a tilt stand for the instrument. To position the handle, press in at both pivot points and turn the handle to the desired position. Several positions are provided for convenient carrying or viewing. The instrument may also be set on the rear panel feet for storage or operation.

B30. State the power requirements and the procedure used to switch voltage ranges on the Tektronix 453 Oscilloscope.

Applying Power. One of the most important considerations prior to using the 453 is to insure that the oscilloscope is connected properly to the correct voltage source. The reason for this is safety for both you and the instrument. Connecting the 453 to the proper voltage source insures that the instrument will work properly and will not be damaged. Grounding the case of an oscilloscope to a known ground enables you to use the 453 or any other oscilloscope safely.

Power requirements. The Type 453 can be operated from either a 115- or 230-volt, 50-400 Hz nominal line. Switching between ranges is automatically accomplished when the correct power cord for the nominal voltage range is installed in the power receptacles on the rear of the instrument. Even though these two differently shaped power receptacles on the rear panel insure a proper connection at the oscilloscope, you should make sure that the voltage source that you are plugging the oscilloscope into is of the correct value.

Range switch. In addition to the power receptacles on the rear panel, there is a HIGH-LOW voltage selector switch. This switch is positioned by you, the operator, according to the actual value of the 115- or 230-volt source. For example, the actual value of a 115-volt source may range as much as ±20 volts (95 volts to 135 volts) or greater. If the input voltage is between 96–127 volts for a 115-volt source or between 192–254 volts for a 230-volt source, the LOW range is selected. The HIGH position is selected when the input voltage is between 103–137 volts for a 120-volt source or between 206–274 volts for a 230-volt source. It should be noted that the LOW and HIGH range for each category overlap. The correct procedure would be to position the range switch according to the following conditions:

a. For a 115-volt source
  (1) Use the LOW range for 102 volts or lower.
  (2) Use the HIGH range for 103 volts or higher.

b. For a 230-volt source
  (1) Use the LOW range for 205 volts or lower.
  (2) Use the HIGH range for 206 volts or higher.

Exercises (B30):

1. Give the two line voltages to which the Type 453 can be connected.

2. If you have a 230-volt line source that measures 204 volts, in what position should you place the HIGH-LOW range switch on the rear panel?

B31. Identify the types of probes used with the oscilloscope, state the loading effect of probes, and indicate how a probe is adjusted.

Use of Probes. Now that you have applied power and grounded the oscilloscope, you are ready to connect the oscilloscope to a signal. This signal may be the output of an amplifier that you want to check for the amount of amplitude and to see if the output is distorted. To connect the oscilloscope to the test signal you must use some type of probe.

Types of probes. There are mainly four types of probes:
  (1) Unshielded leads.
  (2) Straight coaxial leads.
  (3) 1:1 probes.
  (4) 10 X attenuator probes.

Select the proper probe according to the amplitude and frequency of the test signal being measured. Loading effects to the test signal must also be considered.

Signal connections and loading. In general, 10 X attenuator probes offer the most convenient means of connecting a signal to the input of the Type 453. A 10 X attenuator probe offers a higher input impedance and allows the circuit under test to perform more closely to actual operating conditions. However, the 10 X attenuator probe also attenuates the input signal 10 times. The probe is shielded to prevent pickup of electrostatic interference. Low-frequency response with AC input coupling is extended to about 0.16 Hz (30 percent down).

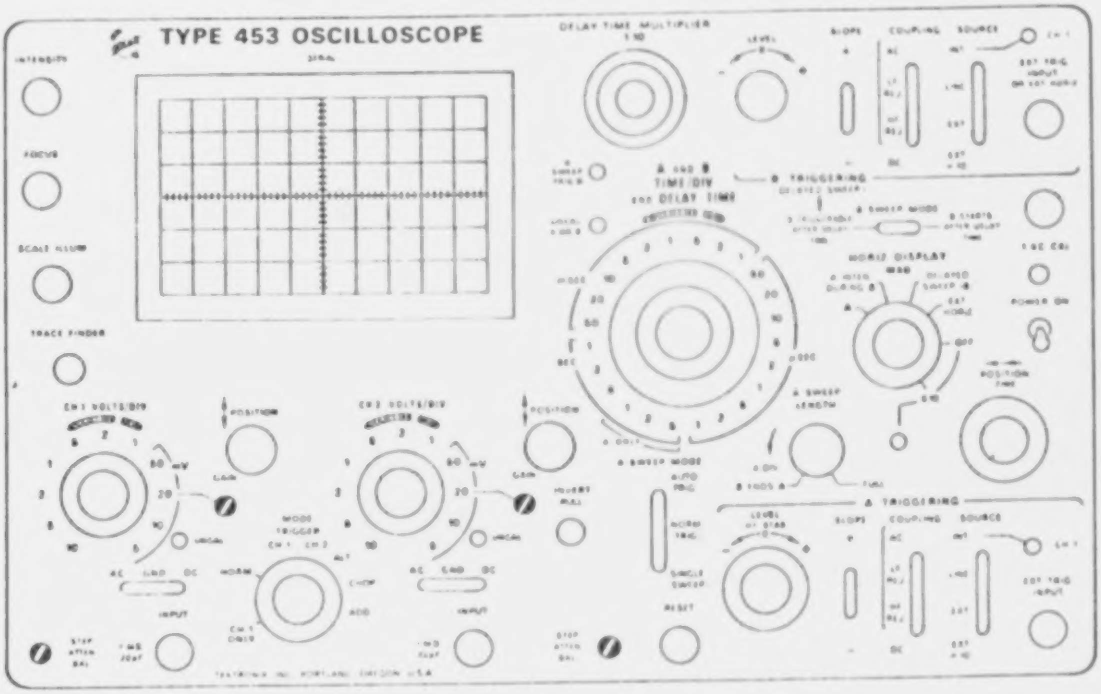
In some cases, the signal can be connected to the type 453 with short unshielded leads. This is particularly true with high-level, low-frequency signals. When such leads are used, be sure to establish a common ground between the Type 453 and the equipment under test. Attempt to position the leads away from any source of interference to avoid errors in the display. If interference is excessive with unshielded leads, use a coaxial cable or probe.

In high-frequency applications requiring maximum overall bandwidth, use a coaxial cable terminated in its characteristic impedance at the Type 453 INPUT connector.

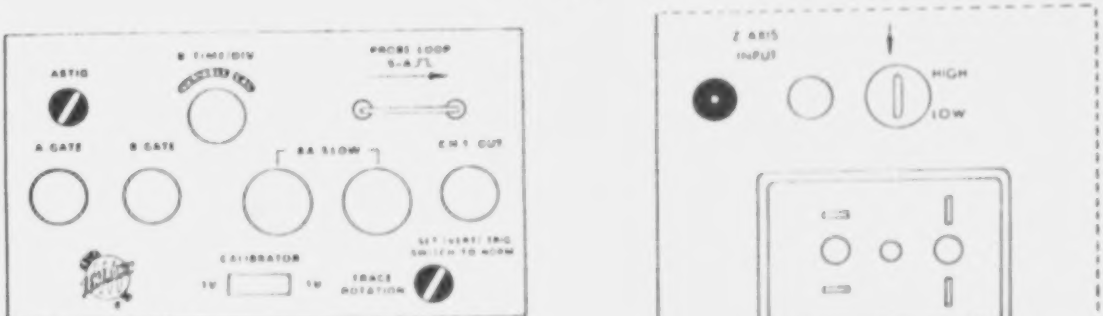
As nearly as possible, simulate actual operating conditions in the equipment under test. Otherwise the equipment under test may not produce a normal signal. The 10 X attenuator probes mentioned previously offer the least circuit loading. Tektronix 10 X attenuator probes have an input resistance of about 10 megohms with very low shunt capacitance.

When the signal is coupled directly to the input of the Type 453, the input impedance is about 1 megohm paralled by about 20 pf. When the signal is coupled to the input through a coaxial cable, this cable can increase the input capacitance to well over 100 pf.

Adjusting a probe. Before using a 10 X attenuator probe, you must check (and adjust if necessary) the compensation of the probe in order to prevent distortion of the applied waveform. After adjusting the oscilloscope for about 2 or 3 cycles, you should have a perfect square wave displayed. If there is distortion of the 1 kc square wave, the variable capacitor within the 10 X attenuator probe needs adjusting. To adjust the probe, first unlock the locking sleeve by turning it counterclockwise. Then compensate the probe by rotating its body while you watch the scope display for the desired waveform. When this compensation has been completed, carefully turn the locking sleeve clockwise to lock it without disturbing the adjustment of the probe.


TYPE 453 OSCILLOSCOPE
INTENSITY
FOCUS
SCALE ILLUM
TRACE FINDER
DELAY TIME MULTIPLIER
LEVEL
SLOPE
COUPLING
SOURCE
A AND B TIME/DIV AND DELAY TIME
B TRIGGERING
HORIZ DISPLAY
POWER ON
A SWEEP LENGTH
POSITION
CH 1 VOLTS/DIV
CH 2 VOLTS/DIV
MODE TRIGGER
CH 1
CH 2
ALT
NORM
CHOP
ADD
AC
GND
DC
INPUT
INVERT PULL
A SWEEP MODE
AUTO TRIG
NORM TRIG
SINGLE SWEEP
RESET
A TRIGGERING
TEKTRONIX INC PORTLAND OREGON USA

a Front panel


ASTIG
B TIME/DIV
PROBE LOOP
A GATE
B GATE
CH 1 OUT
CALIBRATOR
1V
TRACE ROTATION
SET INVERT TRIG SWITCH TO NORM
Z AXIS INPUT
HIGH
LOW
115V AC
230V AC
50 400 ~

b Side panel

c Rear panel

Figure 6-6. Type 453 oscilloscope.

Exercises (B31):

1. What types of probes are used with the oscilloscope?

2. What type of probe should you use for a high-level, low-frequency signal?

3. What is the input impedance of the Type 453?

4. Briefly indicate how the 10 X attenuator probe is adjusted.

B32. Briefly state the function of some of the controls and connectors on the 453 Oscilloscope.

Controls. The following paragraph is a list of the controls and connectors on the 453 Oscilloscope. While reading this paragraph, refer to figure 6-6 for their location on the 453. You will use all of the controls and connectors except the screwdriver adjustments. These adjustments are to be made only by qualified PME laboratory personnel. The PME laboratory is responsible for the repair and calibration of this type of test equipment.

The controls and connectors are as follows:
a. Front Panel:

INTENSITY	Controls brightness of display. Provides adjustment for a well-defined display.
FOCUS	Controls graticule illumination.
SCALE ILLUM	Returns the display to the screen, when pressed, by reducing horizontal and vertical deflection.
TRACE FINDER	Used to locate trace which exceeds scan of display area.
VOLTS/DIV	Selects vertical deflection factor (VARIABLE control must be in CAL position for indicated deflection factor).
VARIABLE	Provides continuously variable deflection factor to at least 2.5 times setting of VOLTS/DIV switch.
POSITION GAIN	Controls vertical position of trace. Screwdriver adjustment to set gain of the VERTICAL Pream. Line between adjustment and 20 mV VOLTS/DIV position indicates that gain should be set with VOLTS/DIV switch in this position.
AC GND DC	Selects method of coupling input signal to grid of input amplifier. AC: DC component of input signal is blocked. Low frequency limit (30 percent down) is about 1.6 Hz. GND: Input circuit is grounded (does not ground applied signal). DC: All components of the input signal are passed to the input amplifier.
STEP ATTEN BAL	Screwdriver adjustment to balance input amplifer in the 5, 10, and 20 mV positions of the VOLTS/DIV switch.
INPUT MODE	Vertical input connector for signal. Selects vertical mode of operation. CH 1: The Channel 1 signal is displayed. CH 2: The Channel 2 signal is displayed. ALT: Dual trace display of signal on both channels. Display switched at end of each sweep. CHOP: Dual trace display of signal on both channels. Approximately 1 microsecond segments from each channel displayed at a repetition rate of about 500 kHZ. ADD: Channel 1 and 2 signals are algebraically added and the algebraic sum is displayed on the CRT.
TRIGGER	Selects source of internal triggering signal from vertical system. NORM: Sweep circuits triggered displayed channel(s). Channel 1 signal available at CH 1 OUT connector. CH 1 ONLY: Sweep circuits triggered only from signal on Channel 1. No signal available at CH 1 OUT connector.
INVERT	When pulled out, inverts the Channel 2 signal.
EXT TRIG INPUT	Input connector for external triggering signal. Connector in B TRIGGERING section of front panel also serves as external horizontal input when HORIZ DISPLAY switch is in EXT HORIZ position.
SOURCE	Selects source of triggering signal. INT: Internal triggering provided from vertical system. When CH 1 light is on, triggering signal is obtained only from the Channel 1 input signal; when the light is off, triggering is obtained from displayed channel(s). Source of internal trigger signal is selected by the TRIGGER switch. LINE: Sweep triggered at line frequency. EXT: Sweep triggered from signal applied to EXT TRIG INPUT connector. EXT ÷ 10: Attenuates external signal 10 times.

COUPLING	Determines method of coupling triggering signal to trigger circuit. AC: Rejects DC and attenuates signals below 30 Hz. LF REJ: Rejects DC and attenuates signals below 30 kHz. HF REJ: Passes signals between 30 Hz and 50 kHz; rejects DC and attenuates signals outside the above range. DC: Accepts AC and DC signals.
SLOPE	Selects portion of triggering signal which will trigger sweep. +: Sweep triggered from positive-going portion of triggering signal. −: Sweep triggered from negative-going portion of triggering signal.
LEVEL	Selects amplitude point on triggering signal where sweep is triggered.
HF STAB	Provides stable display for signals above about 10 MHz at sweep rates of 10 or 20 manoseconds/division (MAG switch set to X10). Has negligible effect at lower sweep rates. (A sweep only.)
DELAY-TIME MULTIPLIER	Provides variable sweep delay between 0.50 and 10.00 times and the delay time indicated by the A TIME/DIV switch.
A SWEEP TRIG'D	Light indicates that A SWEEP is triggered and will produce a stable display with correct INTENSITY and HORIZONTAL POSITION control settings.
UNCAL A OR B	Light indicates that either A or B VARIABLE control is not in the CAL position.
A AND B TIME/DIV	A TIME/DIV switch selects the sweep rate of the A SWEEP circuit and selects the basic delay time (to be multiplied by DELAY TIME MULTIPLIER setting). B TIME DIV (DELAYED SWEEP) switch selects sweep rate of the B SWEEP circuit. VARIABLE controls must be in the CAL position for calibrated sweep rate.
A VARIABLE	Provides continuously variable sweep rate to at least 2.5 times setting of A TIME/DIV switch. Sweep rate is calibrated when control is set fully clockwise to CAL.
B SWEEP MODE	Selects B sweep operation mode. B TRIGGERABLE AFTER DELAY TIME: B sweep circuit will not produce a sweep until a trigger pulse is received following the delay time selected by the DELAY TIME A TIME/DIV) switch and the DELAY TIME MULTIPLIER dial. B STARTS AFTER DELAY TIME: B sweep circuit runs immediately following delay time selected by the DELAY TIME switch and DELAY TIME MULTIPLIER dial.
HORIZ DISPLAY	Selects horizontal mode of operation. A: Horizontal sweep provided by A sweep. B sweep is inoperative. A INTEN DURING B: Sweep rate determined by A TIME/DIV switch. An intensified portion, length of what is about 10 times setting of B TIME/DIV switch, will appear on the sweep. This provides a check of the duration and position of B sweep with respect to A sweep. DELAYED SWEEP (B): Sweep rate determined by B SWEEP MODE switch. EXT HORIZ: Horizontal deflection provided by an external signal.
MAG	Increases sweep rate to 10 times setting of A or B TIME/DIV switch by horizontal expanding the center division of the display. Light indicates when magnifier is on.
A SWEEP MODE	Determines A sweep operation mode. AUTO TRIG: Each sweep may be triggered in the normal manner when the triggering signal repetition rate is about 20 Hz. For lower repetition rates or when there is no triggering signal, the sweep generator free runs to produce a bright reference trace at all sweep rates. NORM TRIG: Sweep is triggered from an internal or external signal using the A TRIGGERING controls. SINGLE SWEEP: Displays one sweep and then shuts off until reset.
RESET	When light is on, the sweep is ready to produce a display when a trigger is received (SINGLE SWEEP mode). After a sweep is completed, the RESET button must be pressed before another sweep can be presented.
A SWEEP LENGTH	Adjusts length of A sweep. In the FULL position (clockwise detent), the sweep is about 11 divisions long. As the control is rotated counterclockwise, A sweep length will be reduced until it is less than 4 divisions long just before the detent in the fully counterclockwise position is reached. In the B ENDS A position (counterclockwise detent), the A sweep is reset at the end of the B sweep. This provides the fastest possible sweep repetition rate for delayed sweep signals.
POSITION FINE	Controls horizontal position of trace. Provides more precise horizontal position adjustment.
1 KC CAL	Calibrator output connector.
POWER ON	Light: Indicates that POWER switch is on and the instrument is connected to a line source. Switch: Applies power to the instrument.

b. Side Panel:

ASTIG	Screwdriver adjustment used in conjunction with the FOCUS control to obtain a well-defined display. Does not require readjustment in normal use.

B TIME/DIV VARIABLE	Provides continuously variable sweep rate to at least 2.5 times setting of B TIME/DIV switch. Sweep rate is calibrated when control is fully clockwise to CAL.
PROBE LOOP	Current loop providing 5-milliamp squarewave current from calibrator circuit.
A GATE	Output connector providing a rectangular pulse coincident with A sweep.
B GATE	Output connector providing a rectangular pulse coincident with B sweep.
.8A SLOW	Fuses for line.
CH 1 OUT	Output connector providing signal output from Channel 1 when the TRIGGER switch is in the NORM position.
CALIBRATOR	Switch selects output voltage of calibrator. 1-volt or 0.1-volt square wave is available.
TRACE ROTATION	Screwdriver adjustment to align trace with horizontal graticule lines.

c. Rear Panel

Z AXIS	Input connector for intensity modulation of the CRT display.
INPUT POWER	Input connector for line power. Left part of connector is for 115-volt input; right part is for 230-volt input. Instrument automatically switched between ranges when correct power cord is installed.
HIGH-LOW	Selects line-voltage regulating range of low-voltage power supplies.

Exercises (B32):

1. What is the function of the TRACE FINDER control?

2. Which mode must be selected to display dual trace on the 453 Oscilloscope?

3. Whose responsibility is it to adjust the STEP ATTEN BAL control?

4. What is the function of the A and B sweep, A VARIABLE control?

5. What control varies the amplitude of the 1 KC CAL?

6. What type of fuse does the 453 use?

7. What light must remain out in order to make accurate voltage measurements?

B33. Explain selected steps of the procedure used to measure a peak-to-peak AC voltage using the 453 Oscilloscope, and convert peak-to-peak AC voltages to RMS voltages.

Voltage Measurement. If you were troubleshooting a circuit with an oscilloscope, the AC signal displayed would be in the form of a sine wave. The amplitude of this sine wave would not be the same as that measured with a multimeter. On the oscilloscope the AC signal would be represented as a peak-to-peak signal, whereas the voltage represented on the multimeter is an RMS voltage reading. Because the technical order that you are troubleshooting with may give either peak-to-peak or RMS values, you must be able to proficiently read a peak-to-peak value on the oscilloscope and convert this reading to an RMS value.

Peak to peak. To make a peak-to-peak voltage measurement, use the following procedure:

(1) Connect the signal to either INPUT connector.

(2) Set the MODE switch to display the channel used.

(3) Set the VOLTS/DIV switch to display about 5 division of the waveform.

(4) Set the AC GND DC switch to AC. NOTE: For low-frequency signals below about 16 Hz, use the DC position.

(5) Set the A TRIGGERING controls to obtain a stable display. Set the TIME/DIV switch to a position that displays several cycles of the waveform.

(6) Turn the vertical POSITION control so that the lower portion of the waveform coincides with one of the graticule lines below the centerline and the top of the waveform is on the viewing area. With the horizontal POSITION control, move the display so that one of the upper peaks lies near the vertical centerline.

(7) Measure the divisions peak-to-peak vertical deflection. Make sure the VARIABLE VOLTS/DIV control is in the CAL position so you will know what multiplication factor to use in the next step. (NOTE: This technique may also be used to make measurements between two points on the waveform rather than peak to peak.)

(8) Multiply the distance measured in step 7 by the VOLTS/DIV switch setting. Also include the attenuation factor of the probe, if any.

EXAMPLE: Assume a peak-to-peak vertical deflection of 4.6 divisions using a 10 X attenuator probe and a VOLTS/DIV switch setting of .5. Use the formula:

$$\text{Volts peak to peak} = \text{vertical deflection (divisions)} \times \text{VOLTS/DIV setting} \times \text{probe attenuation factor}$$

Substitute the given values:

$$\text{Volts peak to peak} = 4.6 \times 0.5 \times 10$$

The peak-to-peak voltage would be 23 volts.

RMS. Prior to converting this peak-to-peak voltage of 23 volts, first convert the peak-to-peak voltage to peak voltage. Use the formula:

$$\text{Peak to peak} = 2 \text{ peak}$$

or

$$\text{Peak} = \frac{\text{peak to peak}}{2}$$

Substitute given values:

$$\text{Peak} = \frac{23}{2} = 11.5 \text{ volts.}$$

RMS voltage is the same as effective voltage. Use the formula:

$$\text{Effective voltage (RMS)} = .707 \times \text{peak.}$$

Substitute the given values:

$$\text{Effective voltage} = .707 \times 11.5$$
$$\text{Effective voltage} = 8.13 \text{ volts}$$

Exercises (B33):

1. How should you position the AC GND DC switch if the frequency of the input signal is below 16 Hz?

2. Why must the VARIABLE VOLTS/DIV control be in the CAL position when measuring a peak-to-peak signal?

3. What is the peak-to-peak and RMS value of a voltage whose vertical deflection on the oscilloscope is 5 divisions and the VOLTS/DIV switch is 2?

4. What is the peak-to-peak and RMS value of a voltage whose vertical deflection on the oscilloscope is 4 when a 10 X attenuator probe is used and the VOLTS/DIV switch setting is 5?

B34. Explain selected steps of the procedure used to measure instantaneous voltage (DC) using the 453 Oscilloscope, and convert instantaneous readings on the oscilloscope to DC voltages.

DC Measurement. To measure the DC level at a given point on a waveform, use the following procedure:

(1) Connect the signal to either INPUT connector.

(2) Set the MODE switch to display the channel used.

(3) Set the VOLTS/DIV switch to display about 5 divisions of the waveform.

(4) Set the AC GND DC switch to GND.

(5) Set the A SWEEP MODE switch to AUTO TRIG.

(6) Position the trace to the bottom line of the graticule or other reference line. If the voltage is negative with respect to ground, position the trace to the top line of the graticule. Do not move the vertical POSITION control after this reference line has been established. NOTE: To measure a voltage level with respect to another voltage rather than ground, made the following changes in step 6. Set the AC GND DC switch to DC. Apply the reference voltage to the INPUT connector and position the trace to the reference line.

(7) Set the AC GND DC switch to DC. The ground reference line can be checked at any time by switching to the GND position.

(8) Set the A TRIGGERING controls to obtain a stable display. Set the TIME/DIV switch to a setting that will display the desired waveform.

(9) Measure the distance in divisions between the reference line and the point on the waveform at which the DC level is to be measured.

(10) Establish the polarity of the signal. If the waveform is above the reference line, the voltage is positive; below the line, negative (INVERT switch pushed in if using Channel 2).

(11) Multiply the distance measured in step 9 by the VOLTS/DIV switch setting. Include the attenuation factor of the probe, if any.

As an example, assume that the vertical distance measured is 4.6 divisions and the waveform is above the reference line and you are using a 10 X attenuator probe and a VOLTS/DIV setting of 2.

Use the formula:

$$\text{Instantaneous voltage} = \begin{array}{c}\text{vertical}\\ \text{distance}\\ \text{(divisions)}\end{array} \times \text{polarity} \times \begin{array}{c}\text{VOLTS/}\\ \text{DIV}\\ \text{setting}\end{array} \times \begin{array}{c}\text{Probe}\\ \text{attenuation}\\ \text{factor}\end{array}$$

Substitute the given values:

$$\text{Instantaneous voltage} = 4.6 \times +1 \times 2 \times 10$$

The instantaneous voltage would be +92 volts.

Exercises (B34):

1. How many divisions should be used when measuring DC voltages using the 453 Oscilloscope?

2. How is a DC voltage referenced to another DC voltage?

3. How is polarity affected by using Channel 2?

4. What would be the value of the voltage given in the example in the text if the number of divisions were 4.1 and a 1:1 probe were used?

5. If the instantaneous DC display is 3.8 divisions below the reference line when measured with a 10 X attenuator probe, what is the value of the DC voltage when the VOLTS/DIV setting is 5?

B35. Explain selected steps of the procedure used to measure time duration using the 453 Oscilloscope, and convert time duration measurements to frequency measurements.

Frequency Measurement. Frequency measurements cannot be made directly off the oscilloscope display. First, you must measure the time duration of one cycle. Next, using the proper formula, convert the time of one cycle into the proper frequency. This procedure is not limited to sine waves but can be used for any recurring waveform.

Time duration. To measure time between two points on a waveform, use the following procedure.

(1) Connect the signal to either INPUT connector.

(2) Set the MODE switch to display the channel used.

(3) Set the VOLTS/DIV switch to display about 5 divisions of the waveform.

(4) Set the A TRIGGERING controls to obtain a stable display.

(5) Set the TIME/DIV switch to the fastest sweep rate that will display less than 8 divisions between the time measurement points.

(6) Adjust the vertical POSITION control to move the points between which the time measurement is made to the horizontal centerline.

(7) Adjust the horizontal POSITION control to move the starting point of time measurement area to the first graticule line.

(8) Measure the horizontal distance between the time measurement points. Be sure the A VARIABLE control is set at CAL.

(9) Multiply the distance measured in step 8 by the setting of the TIME/DIV switch. If sweep magnification is used, divide this answer by 10.

As an example, assume that the distance between the time measurement points is 5 divisions and the TIME/DIV switch is set to .1 msec with the magnifier off. Use the formula:

$$\text{Time duration} = \frac{\begin{array}{c}\text{Horizontal}\\ \text{distance}\\ \text{(division)}\end{array} \times \begin{array}{c}\text{TIME/DIV}\\ \text{setting}\end{array}}{\text{magnification}}$$

Substitute the given values:

$$\text{Time duration} = \frac{5 \times 0.1 \text{ msec}}{1}$$

The time duration would be 0.5 milliseconds.

Frequency. The frequency of a periodically recurrent waveform can be determined as follows:

(1) Measure the time duration of one cycle of the waveform as described in the previous paragraph.

(2) Frequency of a signal is the reciprocal of the time duration of one cycle.

As an example, the frequency of a signal that has a time duration of 0.5 milliseconds would be:

$$\begin{aligned}\text{Frequency} &= \frac{1}{\text{time duration}}\\ &= \frac{1}{0.5 \times 10^{-3}}\\ &= 2 \text{ kHz.}\end{aligned}$$

Exercises (B35):

1. Can frequency be measured directly off the 453 Oscilloscope? Why?

2. In the time duration measurement, how is the TIME/DIV switch set?

3. Which graticule should be used for the starting point when using the 453 Oscilloscope for time duration measurement?

4. What is the frequency of a waveform that is 0.3 milliseconds in duration?

5. With a TIME/DIV setting of .2 msec and the magnifier off, what is the frequency of a signal that is 6.8 divisions wide on the oscilloscope?

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ANSWERS FOR EXERCISES

CHAPTER 1

Reference:

A01 - 1. To serve as drains for the static chamber.
A01 - 2. Because of a venturi action produced by openings in the fuselage.
A01 - 3. By a static vent installed on each side of the aircraft.
A01 - 4. To retard corrosion between two dissimilar metals, such as those of the pitot tube and boom.
A01 - 5. Consult the technical order for that particular aircraft.

A02 - 1. (1) Instrument error, caused by mechanical error within the indicator; (2) installation error, caused by the location and manner in which the tube is installed; and (3) density error, caused by increased altitudes and changing temperatures.
A02 - 2. A correction card for the indicator you are using.
A02 - 3. Altitude and free-air temperature.

A03 - 1. Methyl chloride.
A03 - 2. As temperature increases, the temperature diaphram expands, speeding up the pointer movement by shortening the radius of rotation of the intermediate shaft. This gives a true airspeed indication. With a decrease in temperature, the diaphram contracts, and the sequence of events is the reverse.

A04 - 1. It constantly shows the maximum-allowable-airspeed for the particular aircraft at the existing flight altitude.
A04 - 2. As altitude increases, the altitude aneroid in the maximum-allowable-airspeed indicator expands. This action is picked up by the lever of the Mach rocking shaft and is transmitted to the rocking shaft to the sector and rocking shaft assembly. The ratio of movement depends upon the Mach set into the Mach number mechanism. The sector meshes with the handstaff pinion, which causes the barber-pole pointer to move as altitude increases, giving an indication of maximum-allowable airspeed.

A05 - 1. Airspeed diaphram and altitude aneroid.

A06 - 1. In terms of indicated airspeed and Mach number.
A06 - 2. In the Mach number computer system, both the true-airspeed and the machmeter indicator mechanism are driven by motors.
A06 - 3. The gear train housing, differential pickup, and static pressure pickup.
A06 - 4. The static pressure pickup, the differential pressure pickup, and the temperature pickup.
A06 - 5. For each additional master indicator used with the C-2 computer, another amplifier must be added.

A07 - 1. To give the pilot an indication of how high the aircraft is flying.
A07 - 2. The large pointer of the altimeter must make 20 revolutions to indicate an altitude change of 20,000 feet.
A07 - 3. Sea level is the standard from which we measure altitude and pressure. Sea level pressure in the standard atmosphere is equal to 29.92 inches of mercury, with the temperature at 15° Celsius.
A07 - 4. Pressure altitude variation is the difference in height between the points where certain pressures should occur and where they actually do occur at the time of observation.
A07 - 5. To show height indications according to the pressure changes, as set down in the standard atmosphere.
A07 - 6. Prior to takeoff, in flight, and prior to landing.
A07 - 7. Zero altitude.

A08 - 1. It creates a magnetic coupling to drive the handstaff assembly. This arrangement eliminates the need of having a pointer shaft extend through the airtight instrument case.
A08 - 2. The pointer is moved by the diaphram.
A08 - 3. The diffuser.
A08 - 4. It is a temperature-compensating mechanism.
A08 - 5. Clockwise.

A09 - 1. Mechanical, hysteresis, temperature, and installation error.
A09 - 2. The difference between the altimeter reading and a known standard.
A09 - 3. The difference in readings as the altimeter is rotated.
A09 - 4. A range-compensating fork.

A10 - 1. The MB-1.
A10 - 2. The rate at which you change from one airspeed or altitude setting can be set in and controlled by the test set.

A11 - 1. A leak check.
A11 - 2. Tighten line connections or replace the line by sections until the leak is stopped.
A11 - 3. This is done using the TTU-205 at the airspeed and altitude settings given in the TO. You put the leak test switches on the TTU-205 to the leak test position. The amount of leakage, if any, should not exceed the tolerances listed in the TO.
A11 - 4. To remove error caused by friction between moving parts.
A11 - 5. Two, one going upscale and the other going downscale. The differences in the readings at each test point is called hysteresis error.

CHAPTER 2

A12 - 1. High altitude; supersonic.
A12 - 2. -1000 feet to +80,000 feet.
A12 - 3. To supply corrected altitude information to the servoed altimeters and the IFF transponder.
A12 - 4. 115; 400; total; static pressure.
A12 - 5. By replacing an easily accessible two-dimensional, static-pressure defect error correction cam.
A12 - 6. Their operation on a null principle eliminates errors caused by voltage supply variations and normal frequency changes.
A12 - 7. The ground control center can obtain altitude information from an aircraft with an AIMS by the AIMS computer encoder supplying a digital altitude output in 100-foot increments to the aircraft transponder. The airborne transponder automatically relays the information in the form of a pulse train to the ground control center upon interrogation. The information is displayed to the ground control center on a radar screen. Aircraft altitude is determined through the round-trip transit time of the interrogation pulse.
A12 - 8. The failure circuit removes power from the AAU-19A altimeter and opens the common lead to the encoder. Also, a warning light on the pilot's panel illuminates, and an audio tone is heard in the headset. At the same time, the AIMS altimeters automatically revert to the stand-by mode of operation.
A12 - 9. Null.
A12 - 10. To eliminate "nuisance" switching which might be caused by turbulent air or momentary power transients.

A13 - 1. The operating ranges are different.
A13 - 2. A two-phase motor in the CPU-66/A computer.
A13 - 3. A pair of aneroids and an airspeed diaphram.
A13 - 4. The airspeed diaphram's height decreases.
A13 - 5. Approximately 40°.
A13 - 6. It allows for a high degree of sensitivity by multiplying the motion of the rocking shaft by 10 to prevent any ambiguous condition from occurring.

A13 - 7. ±60°.
A13 - 8. The system can withstand with a step pressure input equivalent to full-scale operation without damage to the mechanism.
A13 - 9. To compute Mach numbers and provide log $\frac{Pt}{Pt}$ torque to the O.- shaft.

A13 - 10. Allow for limited friction-free angular rotation and backlash.
A13 - 11. It allows the aneroid errors, synchro errors, and similar errors to be calibrated out of the system.
A13 - 12. By angling the surface of the nut so that moving the nut will cause a displacement of the frame arm greater or less than that due to the pitch of the lead screw.
A13 - 13. A hairspring for backlash and an eccentric for gear center adjustment.
A13 - 14. A mechanical offset rotation of the microsyn rotor.
A13 - 15. A failure in the primary power, amplifier, motor, or power transformer; a servo follow-up error; a servo gear train seizure or failure; gross tracking error, or a specific component failure in the power supply.

A14 - 1. The AAU-19 A altimeter, when coupled to a computer, provides (1) a system designed to meet the requirements for all aircraft and air traffic control radar beacon systems and (2) an automatic standby system in the event of failure or power loss.
A14 - 2. The servo will drive the pointers to the true position and override the aneroid system.
A14 - 3. The AAU-19/A altimeter automatically reverts to standby mode.
A14 - 4. When there is a difference between the indicator and transmitter synchros.
A14 - 5. Reduced size and weight, and increased gain.
A14 - 6. A spring.
A14 - 7. Errors due to position, acceleration, and vibration.
A14 - 8. By means of a low-inertia drag cup motor and a brushless low-inertia control transformer.
A14 - 9. The altimeter must be brought to room temperature.

A15 - 1. The TTU-205 and TTU-229/E.
A15 - 2. Inspection of the AIMS consists of checking the altimeter for tightness of cover glass and discoloration and deterioration of instrument and components. All components should be checked for proper mounting and to insure against chaffing. All wires, lines, and connectors should be checked for chaffing, tightness, and lockwiring, if required.

A16 - 1. The TTU-205 and TTU-229/E test sets or TTU-205 and IFF transponder test sets.
A16 - 2. The IFF, Mode C, system.
A16 - 3. RESET mode operation, STBY mode operation, and altimeter vibrator operation.
A16 - 4. A possible shock hazard to personnel.
A16 - 5. It should be operating and indicating the station elevation on the altitude counter when you connect it to the AIMS.
A16 - 6. Seal the static ports with tape using barrier paper or a reversed piece of the tape between the tape and the static ports.
A16 - 7. Apply pitot pressure at a rate NOT EXCEEDING 100 knots per minute at static pressure at not more than 5000 feet per minute.
A16 - 8. 29.92.
A16 - 9. STBY.
A16 - 10. 75 feet.

A17 - 1. TTU-205, TTU-229/E, and a multimeter.
A17 - 2. You would perform a scale error check on the computer; the two altitude outputs should be within 20 feet of each other.
A 17 - 3. A leak or an obstruction in a static line; or, if in primary operation, possibly a defective computer.

A18 - 1. The apparent speed of an aircraft in reference to ambient air.
A18 - 2. The actual speed of an aircraft in reference to ambient air.

A19 - 1. A bellows with a pressure of 3-5 microns and containing no liquid.
A19 - 2. A bellows which contains a pressure less than atmospheric at sea level (29.92" Hg A).
A19 - 3. A nonevacuated, vented bellows used to sense a pressure differential by application of pressures on the inside as well as the outside of the assembly.

A20 - 1. Pressure measured against the reference of a complete vacuum (0" HgA).
A20 - 2. The equivalent altitude in feet for a given barometric pressure in the standard atmosphere.
A20 - 3. The force at which the air impacts the front edges of a moving aircraft.

A21 - 1. The atmospheric pressure sensed by static ports.
A21 - 2. The total air pressure (static pressure plus impact pressure) on the leading (front) surfaces of a flying aircraft.

A22 - 1. Ambient temperature, the temperature of the air through which the aircraft is flying.
A22 - 2. Temperature of the static ambient air plus the compression temperature rise of the air due to the velocity of a moving object (ram temperature rise).

A23 - 1. Pneumatic true static pressure from the SPC or indicated static pressure when the SPC is inoperative.
A23 - 2. One shaft rotation proprotional to Ps and one shaft rotation proportional to natural logrithm static pressure (LnPs) altitude; also, one transformer output proportional to Δ LnPs from any given engagement altitude.

A24 - 1. The SPC corrects for static port sensing errors.
A24 - 2. A correction signal which is a function of Mach number and/or indicated angle of attack.

A25 - 1. A shaft rotation which is the algebraic sum of the rotation of the two input shafts.
A25 - 2. To facilitate solving problems by addition, subtraction, multiplication, or division of the logarithms of various functions and to apply corrections to output shafts.

A26 - 1. True static pressure from the SPC or indicated static pressure when the SPC is inoperative. It also recieves total pressure from the pitot tube.
A26 - 2. A gear rotation proportional to the ratio of Pt to Ps or Psi.

A27 - 1. There are three inputs to the gearbox module in the form of shaft rotations. The shaft rotations are proportional to Ps, LnPs, and Ps/Pt respectively.
A27 - 2. Three voltage ratios - one proportional to Ps, one proportional to LnPs, and one proportional to Qc; one gear rotation which is proportional to Ps/Pt; and a synchro control transformer output which is proportional to Δ Mach from a given lock-in point.

A28 - 1. The PRT via the gearbox.
A28 - 2. All Mach or Mach function information.

A29 - 1. Electrical signals analogous to function of Mn and Tti.
A29 - 2. As a variable resistance network.

A30 - 1. Pneumatic intelligence inputs and electrical outputs.

A31 - 1. The LPC input is a pneumatic Ps and its outputs are altitude (LnPs) and pressured (Ps) information.
A31 - 2. The continuous winding on the outside legs are wound in opposition to the center leg.
A31 - 3. They are 180° out of phase because of their reversed direction of winding.

A31 - 4. The direction of beam rotation is dependent upon the direction of change in static pressure.
A31 - 5. It causes the fulcrum positions and jackscrew rotations to be very nearly linear with LnPs.

A32 - 1. The Δ LnPs clutch engages the rotor of the synchro control transformer B1 is mechanically connected to the LnPs shaft.
A32 - 2. It is determined by the direction of LnPs change (+ or -).

A33 - 1. In the pressure ratio sensor.
A33 - 2. It is a force proportional to Qc pressure.
A33 - 3. Direction of motor rotation and thus the direction of jackscrew rotation and fulcrum movement.
A33 - 4. So that the proper gear train rotation direction is realized when an error signal is developed.
A33 - 5. The signal from the E-core will be 90° out of phase with the reference leg of the motor. In the opposite direction, the motor will run the other way.
A33 - 6. A tachometer winding in the tachometer generator in the servomotor assembly produces a negative feedback to prevent oscillations and overshooting.

A34 - 1. A force equal to Psi minus case pressure is applied to one end of the beam and a force proportional to case pressure is applied to the opposite end of the beam.
A34 - 2. Two poppet valves operated by the beam control the SPC case pressure.
A34 - 3. Both control valves are closed.
A34 - 4. It determines whether the low- or high-pressure valve will open.

A35 - 1. Psi is routed directly into the Ps lines.
A35 - 2. A relay and also limit switches.
A35 - 3. A time-delay relay.
A35 - 4. 28 VDC will be applied to the coil of K3.
A35 - 5. It prevents the feedback voltage from flowing to ground through the closed switch.
A35 - 6. The fail circuit is manually energized and Psi is supplied to the Ps system.

A36 - 1. True airspeed.
A36 - 2. By a feedback generator.
A36 - 3. They are linear.
A36 - 4. A resistor completes the circuit.

A37 - 1. A rotation proportional to LnQc.
A37 - 2. A suitable spring-load is attached to the output gearing.
A37 - 3. An electrical clutch is energized and the synchro mechanical self-centering device is overridden.

A38 - 1. By two potentiometers in the Mach sector module. The potentiometer wipers are positioned by cams which are driven by the Ps/Pt shaft.
A38 - 2. It is linear.

A39 - 1. It controls the amount of negative feedback.
A39 - 2. 115 volts, 400-Hz, three-phase.
A39 - 3. It provides a source of air for the computer.
A39 - 4. An adjustable load spring.
A39 - 5. Pg follows Ps by a fixed amount.

A40 - 1. Precision variable resistor R21B.
A40 - 2. Precision variable resistor R21A.

A41 - 1. Through the TAS shaft.
A41 - 2. It sends a TAS signal to the TAS shaft and is used as a spare.
A41 - 3. It sends a TAS signal to the TAS shaft that drives the stick force to stabilator.
A41 - 4. 190 knots.

A42 - 1. A Qc signal from precision variable resistor R19B that is actuated through the Qc shaft.
A42 - 2. A Qc output from precision variable resistor R19A that is actuated through the Qc shaft.
A42 - 3. A Qc output from precision variable resistor R19C that is actuated through the Qc shaft.
A42 - 4. It is from precision variable resistor R53C and is actuated through the Tt shaft.

A43 - 1. An LnPs output from precision variable resistor R20E and is actuated through the LnPs shaft.
A43 - 2. 42K feet.
A43- 3. 32K feet.

A44 - 1. A function of Mn output from precision variable resistor R26 and is actuated through a cam on the Ps/Pt shaft and is driven by the PRT.
A44 - 2. A Δ Mn output from synchro B3 that is actuated through a Ps/Pt shaft and is driven by the PRT when the clutch is energized.
A44 - 3. At 0.98 Mach.
A44 - 4. It closes at 0.4 Mach and opens at 0.98 Mach.

A45 - 1. Check each component for physical damage, proper installation, and safetying, and check shock mounts for deterioration.
A45 - 2. When the BIT switch is pressed the At should read 0°, altitude should read 40,000 feet ± 100 feet, and the TAS should read 800 knots ± 30 knots.

A46 - 1. Circuit breakers; external; test; connectors.
A46 - 2. Alphabetical; direct.
A46 - 3. Troubleshooting; location; maintenance.
A46 - 4. NO-YES; malfunction.
A46 - 5. Loose; bent; broken; pins; shielding; ground.
A46 - 6. Operational check; TTU-205.

A47 - 1. The TTU-205.
A47 - 2. AN/ASM-270A or AN/ASM-201B.

A48 - 1. When a new CADC is withdrawn from supply and when one is suspected of malfunctioning on the aircraft.
A48 - 2. Making adjustments of adjustment points and removing and replacing of defective modules.

CHAPTER 3

A49 - 1. A semiuniversally mounted gyroscope has 2° of freedom, whereas a universally mounted gyroscope has 3° of freedom.
A49 - 2. Rigidity is a gyroscopic principle that refers to the tendency of a spinning rotor to maintain a fixed position in space.
A49 - 3. The rotating earth turns under the gyro, and the axis of the gyro appears to tilt.
A49 - 4. Induced precession.
A49 - 5. The gyro rotates around its vertical axis because the reaction is 90° away from the applied force in the direction of rotor rotation.
A49 - 6. An erection system.

A50 - 1. Every 15 minutes.
A50 - 2. To prevent damage on the gyro bearings.
A50 - 3. Through two large bevel gears and a magnetic coupling.

A51 - 1. The low-inertia motor winds a spring and pulls the POWER OFF alarm flag out of view.

A52 - 1. The torquer, the pendulum brush assembly, and the amplifier section.
A52 - 2. Around the horizontal axis.
A52 - 3. Perpendicular to the earth within the operating limits of the gyro.
A52 - 4. An open plate circuit in V_1 does not affect the operation of the gyro. One tube is a backup for the other one; therefore, the erection torquer operates normally and keeps the directional gyro in horizontal position.

A53 - 1. Check operation of the pointer (left knob) and the dial and pointer (right knob).
A53 - 2. Continuity checks, wiring repairs, and component replacement.

A54 - 1. Oscillating tilt table.
A54 - 2. You are checking the gyro for drift.

A55 - 1. The EDAI gyro is mounted with its spin axis perpendicular to the earth's surface.
A55 - 2. The EDAI has 360° of motion about its lateral axis.
A55 - 3. The aircraft.
A55 - 4. The horizon bar moves up or down 27°.
A55 - 5. The power-off flag is operated by a two-phase low-inertia motor.
A55 - 6. Round, rotating magnet, a plate made of nonmagnetic metal, two steel balls, and a ratchet and pawl escapement mechanism.

A56 - 1. To give the pilot a composite pictorial display of roll and pitch flight information on the face of the indicator.
A56 - 2. The rate transmitting gyro.
A56 - 3. It may be mounted on the back of the indicator or may be mounted remotely someplace in the aircraft.
A56 - 4. The control of the third gimbal in the displacement gyro.
A56 - 5. A minimum of 10° in dive and 5° in climb.
A56 - 6. Check the aircraft and the gyro platform (DG) to insure each is level.

A57 - 1. The gyro senses a rate of turn, develops a signal, and transmits the signal to a meter movement in the attitude director indicator.
A57 - 2. By the direction in which the aircraft turns.

A58 - 1. It provides the all-attitude reference system with pitch and roll.
A58 - 2. A vertical gyro (front) and a directional gyro (rear).
A58 - 3. The gyros will give an accurate indication through 360° of aircraft roll and pitch maneuvers.
A58 - 4. The pitch and roll axes.
A58 - 5. A photocell.
A58 - 6. The bearing drive motor rocks the bearing races; thus by rocking the gimbal bearing races back and forth, bearing friction is reduced in the directional gyro.
A58 - 7. A pitch signal from the vertical gyro controls the directional gyro's pitch gimbal.
A58 - 8. The gyro remains fixed and the rotor of the synchro is connected to the outer roll gimbal and moves with the aircraft. The displacement between the rotor (stabilized by the gyro) and stator (moved with outer roll gimbal) introduces a signal into the synchro.

A59 - 1. It controls the position of the vertical gyro pitch gimbal.
A59 - 2. The operation of relays K408 and K409, as shown in figure 3-6.
A59 - 3. The roll signal locks the outer roll gimbal perpendicular to the gyro's frame.

A60 - 1. 180°.
A60 - 2. It controls the operation of pitch phase reversing relays to prefent a reverse roll signal.
A60 - 3. The third gimbal will have completely inverted by 180° in roll.
A60 - 4. The gyros remain fixed (stabilized) in space and during Immelmann turn, the aircraft changes direction by 180°. Since the aircraft changed direction, the synchro that was originally in front is now in the rear and vice versa.
A60 - 5. Stops are placed at approximately 85°.
A60 - 6. CX B221.
A60 - 7. The azimuth and slaving signals.

A61 - 1. Cascade.
A61 - 2. The starting unit.
A61 - 3. Eight relays, four bridge rectifiers, and one power transformer.
A61 - 4. To allow the vertical gyro to erect in its roll and pitch axes, during the first 60 seconds, without the MC-1 having any effect on the erection cycle.
A61 - 5. It would cause the vertical gyro to motorize (spin).
A61 - 6. 115 volts.
A61 - 7. By the switching rate gyro cutting out the signal to the roll erection motor.
A61 - 8. Approximately 60 seconds after power has been applied.
A61 - 9. K1.

A62 - 1. By aligning the compass transmitter.
A62 - 2. To establish an azimuth (direction) reference in the all-attitude reference system.
A62 - 3. The lugs provide the connection for the leads that pass through the case from the transmitter to the compass system.
A62 - 4. It counteracts deviation originating from magnetic aircraft parts located in the vicinity of the transmitter.

A63 - 1. 24.
A63 - 2. Latitude correction corrects for apparent drift by turning the gyro an equal distance to the apparent drift, but in the opposite direction.
A63 - 3. That the slaving and azimuth signals are synchronized.
A63 - 4. By positioning the stator of one synchro (B206) so that its output will be the same as of another synchro (B207).
A63 - 5. To prevent the slew motor from coasting and from developing an error signal.

A64 - 1. Slaving and DG.
A64 - 2. When changing from the Northern to the Southern Hemisphere or vice versa.
A64 - 3. It drives the azimuth card of the horizontal situation indicator (HSI).

A65 - 1. Under a lubber line from the top of the azimuth card.

A66 - 1. The SRG cuts out slaving, roll erection, and pitch erection during turns.
A66 - 2. Cutout action is initiated in turns of 15° or more.
A66 - 3. Roll erection cutout prevents the erection of the vertical gyro to the false vertical due to centrifugal force acting on the fluid in the roll erection switch.

A67 - 1. K101.
A67 - 2. K101.
A67 - 3. Magnetic heading.
A67 - 4. A slaving error signal is developed in the system. Later, through the electrical components, this signal corrects the gyro to its original position.
A67 - 5. In certain areas, the earth's magnetic lines of force are so distorted that a true magnetic heading would not be possible in the slaving mode of operation.
A67 - 6. By adjusting rheostat adjustment R801.

A68 - 1. Phase C is applied to the rotor of CX B153.
A68 - 2. To keep the DG pitch gimbal perpendicular to the earth's surface.
A68 - 3. A pictorial readout in degrees of the aircraft's pitch in relation to the earth's surface.
A68 - 4. It supplies all of the motor-generator units with fixed-phase voltage.
A68 - 5. By B301 through the roll reversing contacts (K405) and the energized contacts of K409 to the roll summing amplifier (A402).

A69 - 1. Because the hermetically sealed components should not be disassembled for inspection.
A69 - 2. An operational check will be performed by using the applicable aircraft technical order.
A69 - 3. 1° to 2° per minute.

A70 - 1. Continuity and voltage checks.
A70 - 2. The switching rate gyro.

A71 - 1. A turntable.
A71 - 2. Two.

A72 - 1. TACAN is a radio facility which provides radials which radiate from the station like spokes from the hub of a wheel. It supplies to the pilot a continuous accurate short slant-range distance, course, and bearing information.
A72 - 2. A ground radio signal sent to the aircraft instrument system to display command information for an intercept mission.
A72 - 3. An angular beam that gives the pilot a fixed angle of descent to the end of the runway.
A72 - 4. The difference between the manually selected course and the actual heading of the aircraft.
A72 - 5. A potentiometer used to adjust for a condition equal or near equal.

A73 - 1. Roll and pitch.
A73 - 2. The ILS approach mode.

A74 - 1. Relays K1 and K4 in the FDC become energized. The bias voltage from the meter movement is removed and the vertical steering pointer is spring-actuated into view.
A74 - 2. It permits a greater allowable bank signal from the bank limit circuit to center the vertical steering pointer.
A74 - 3. At synchro B3 in the HSI.
A74 - 4. The vertical steering pointer would remain out of view in the ADI.
A74 - 5. An open relay K2C in the pitch relay assembly.

A75 - 1. Under the top fixed lubber line that extends through the fixed aircraft on the indicator.
A75 - 2. The deviation bar.
A75 - 3. Relative bearing to the target.
A75 - 4. By a knob marked "HDG SET" or automatically by information from data link.
A75 - 5. When the distance to the destination is greater than 1000 miles.

A76 - 1. The compass, the bearing amplifier, and fixed phase windings of servometers MG2 and MG3.
A76 - 2. When the mode select switch is in manual, data link, or Doppler modes of operation.

A77 - 1. The compass card, bearing pointer, course arrow and counter, deviation bar, to-from arrow, heading marker, and distance counter.
A77 - 2. Manually or by servomotors (command).
A77 - 3. To allow MG4 to control the course arrow and counter.
A77 - 4. By D'Arsonval meter movements.
A77 - 5. The command heading marker would be inoperative.

A78 - 1. To align the FDC.

A79 - 1. To warn that an unreliable signal is being received.
A79 - 2. On the rear of the ADI.
A79 - 3. Make sure that the power is off.

A80 - 1. The diode keeps K1 from being energized in data link mode.
A80 - 2. The vertical steering pointer would not come into view.
A80 - 3. Relay K1 in the roll relay assembly is not energized.

A81 - 1. Manual mode.
A81 - 2. It permits a greater allowable bank signal to be applied to the vertical steering pointer.

A82 - 1. Roll, course error, localizer, glideslope deviation, glideslope flag alarm, and localizer flag alarm.
A82 - 2. Relay K2C is probably defective and did not energize.
A82 - 3. The course error signals originate in the course error CT (B7) of the HSI.
482 - 4. Roll error, course error, and localizer.
A82 - 5. The glideslope warning flag comes into view on the ADI.

A83 - 1. The course error signal.
A83 - 2. The closed contacts prevent course error signals from being applied to the vertical steering pointer and connect the crosswind filter (amplifier filter) into the vertical steering pointer circuits.
A83 - 3. 15°.
A83 - 4. The glideslope signal and the outputs of R2 and R4.
A83 - 5. The horizontal steering pointer remains out of view.

A84 - 1. Visual check of the FDC, ADI, and HSI to insure there are no dents, cracks, or loose or missing parts. Connector plus for tightness and security and wires for loose or frayed places. Check FDC shock mount if it is shock mounted.
A84 - 2. The bearing pointer and the course arrow.
A84 - 3. The command heading to reach the DOPPLER destination.
A84 - 4. The direction the target aircraft is flying.
A84 - 5. The course error signal can only be routed through the FDC when both K3 and K4 are deenergized and the only mode this condition is present in is the ILS INBOUND mode.
A84 - 6. A deviation left or right of the runway course.

A85 - 1. Open wire between variac and indicator or bad variac.
A85 - 2. A defective HSI.
A85 - 3. Defective ADI. Remove and replace the ADI.

A86 - 1. The FDC test set.
A86 - 2. In the tester cover lid.
A86 - 3. In the applicable aircraft technical order.

CHAPTER 4

A87 - 1. Mach safe speed airspeed (MSSA) indicator, MSSA amplifier, altitude vertical-speed (AVS) indicator, and the AVS amplifier.
A87 - 2. 115 volts, 400 Hz, single-phase; 5 volts, 400 Hz, single-phase; and 28-volt DC from the aircraft power source. Also, 100-volt DC from the command data source for data link.

A88 - 1. 115-volt, 400 Hz and 62-volt, 400 Hz.
A88 - 2. To control the operation of the command digital counters. They are energized by 28 volts DC.
A88 - 3. At large servoerrors above 300 Mv.
A88 - 4. Parallel pairs of two diodes each.
A88 - 5. When the course signal is blocked and the servoamplifier is fed a fine signal.
A88 - 6. Square wave.
A88 - 7. By a circuit in the Mach auxiliary amplifier.

A89 - 1. To operate the seven servomotors in the MSSA indicator.
A89 - 2. A four-stage servomagnetic amplifier.
A89 - 3. NPN with the emitter as the common element.
A89 - 4. In phase or 180° out of phase.
A89 - 5. The magnetic amplifier windings are connected in series, but are bucking each other so that with no input signal the output is null.

A90 - 1. Minimum safe speed and g, Mach, and indicated airspeed.
A90 - 2. By markers moving over the tapes in the Mach and IAS sections.
A90 - 3. To allow the pilot to set in commands during the MANUAL mode of flight.
A90 - 4. Seven servomotors.

A91 - 1. To obtain optimum landing speed indication during the final approach.
A91 - 2. A damper adjustment to adjust for sensitivity.
A91 - 3. So that the acceleration forces acting in the vertical direction can be read in relation to the aircraft angle of attack.

A92 - 1. Mach, command Mach, and maximum safe Mach.
A92 - 2. The motor repositions the rotors of the Mach CT to null and the generator provides an electrical feedback to the auxiliary amplifier for rate damping.
A92 - 3. Mechanical stops.
A92 - 4. A slip clutch.
A92 - 5. It allows flexibility and prevents leakage of the gas and nitrogen mixture used in sealing the indicator.

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A92 - 6. It provides a memory device for command Mach when the Mach tape has been driven beyond the field of view.

A92 - 7. When the solenoid relay K1 is energized, one switch breaks the path of the slew switch error signal; the other switch provides a ground for the electronic chopper.

A92 - 8. When the solenoid of relay K2 is energized, one switch provides a path for the DC signal from data link; the other switch provides a path to the indicator for 26-volt AC.

A93 - 1. IAS and command IAS.

A93 - 2. Because a centering synchro is electrically zeroed to drive the servomotor which positions the command IAS marker.

A93 - 3. Because the centering autosyn drives the command IAS marker to the lubber line and drives the command IAS counter.

A94 - 1. For supplying the different excitation voltages for different units in the AVS system.

A94 - 2. They supply the power to the servomagnetic motors that operate the AVS indicator.

A95 - 1. Vertical-speed preamplifier and postamplifiers, quadrature rejection circuit, electronic choppers, switching diodes, and two relays which control the operation of the command altitude.

A95 - 2. To remove the quadrature components of the signal (voltages 90° out of phase with the signal voltage).

A95 - 3. It converts a DC servoerror signal input to a 400 Hz AC output.

A95 - 4. At the time the mode select switch is placed in DATA LINK position.

A96 - 1. Vertical speed and pressure altitude.

A96 - 2. From the CADC and data link reciever.

A96 - 3. Until the position of the potentiometer represents the input signal.

A96 - 4. The vertical-speed marker is disengaged from the drive shaft by an intermittent mechanism any time the marker reaches either end of the fixed scale.

A97 - 1. Altitude and command altitude.

A97 - 2. -1000 to +80,000 feet.

A97 - 3. It repositions the fine and coarse CTs to null and positions the altitude tape to existing altitude.

A97 - 4. To make an altimeter setting on the AVS indicator, first rotate the BARO knob to the existing altimeter setting and then turn the calibration screw until the sensitive altitude tape reads field elevation.

A97 - 5. A followup potentiometer, an electronic chopper, a command altitude amplifier, and a motor-generator set.

A97 - 6. An intermittent mechanism between the differential output shaft and the marker.

A98 - 1. Altitude, command altitude, target altitude, and cabin pressure.

A98 - 2. Sea level to +80,000 feet.

A98 - 3. Mechanical stops.

A99 - 1. A check of indictors for security of mounting, cracked glass, proper lighting, and clarity of scales; a check of the amplifiers for security of mounting and safety wiring of the mount locknuts.

A99 - 2. Any time a component is replaced or a malfunction is suspected.

A99 - 3. Minimum safe speed tape is checked by using a protractor on the AOA vane to check positions. The command marker and counter are checked by manually positioning the slew switches.

B01 - 1. The command Mach marker would be inoperative in the manual slew operation.

B01 - 2. The vertical scale tester supplies and accurate input to the indicators to check the operation and accuracy of the indicators.

CHAPTER 5

B02 - 1. To provide the pilot with a visual indication of the angle of attack and warn him of impending stalls.

B02 - 2. Because air passing over its top curved surface decreases the pressure over the surface.

B02 - 3. A hypothetical line drawn from the leading to the training edge of the wing.

B02 - 4. An angle formed by the wing chord and the relative wing.

B03 - 1. The wing transmitter.

B03 - 2. The angle-of-attack module.

B04 - 1. Components of a resistive bridge circuit.

B04 - 2. The flap-position transmitter.

B05 - 1. On the pilot's control column.

B05 - 2. The throttle input switches.

B06 - 1. So that the stall warning system is accurate and usable with all flap and throttle positions.

B06 - 2. 28 VDC.

B07 - 1. Two.

B07 - 2. A defect in the angle-of-attack circuit.

B08 - 1. First, insure that no power is applied to the system. Disconnect the two plugs on the computer. The resistance between pins A and C of the plug to the AOA transmitter and pins D and F to the stall warning potentiometer should be 1400 ohms ± 10%. With the ohmmeter leads from pins A to B to the AOA transmitter or pins D to E to the stall warning potentiometer, have someone slowly rotate the AOA vane. The reading should vary smoothly from minimum to maximum resistance.

B08 - 2. The system must be calibrated whenever any component is replaced.

B09 - 1. 186,000 miles per second.

B09 - 2. The angle of incidence is the angle between a ray of light striking a surface and the normal.

B09 - 3. The angle of reflection is the angle between the rays of light leaving the surface and the normal.

B10 - 1. The bending of light.

B10 - 2. The angle between the light ray in the glass and the normal.

B10 - 3. To refract light.

B10 - 4. Convex lenses.

B11 - 1. Prisms are used to refract or reflect light rays.

B12 - 1. A bubble and a set of crosshairs.

B12 - 2. Celestial altitudes.

B13 - 1. The silver pin is used to insert the sextant into or remove it from the mount. The black pin locks and holds the sextant in the extended position and must be pulled to retract the sextant.

B13 - 2. 28 volts DC.

B13 - 3. To remove condensed moisture to prevent freezing of the shutter assembly.

B14 - 1. (1) The averager.
(2) The telescope tube.
(3) The body.
(4) The bubble unit.
(5) The eyepiece assembly.

B14 - 2. To accurately compute an average angle for any time interval up to 2 minutes.

B15 - 1. From -10° to +92°.

B15 - 2. The altitude control knob.

B15 - 3. To focus the bubble image.

B16 - 1. The diffuser lever.

B16 - 2. The bubble control knob is slowly positioned to the full INCREASE BUBBLE position.
B16 - 3. Plus or minus 2 diopters.

B17 - 1. 2 minutes.
B17 - 2. The shutter closes to indicate the completion of a shot.
B17 - 3. Viewed through the eyepiece, true heading is read from the azimuth scale.
B17 - 4. The arrows indicate the direction the index must be moved to return it to the starting point.

B18 - 1. Index and inherent error.
B18 - 2. Range and curve.

B19 - 1. ± one tenth of a degree.
B19 - 2. Adjustment of the projection lens.

CHAPTER 6

B20 - 1. PMEL.
B20 - 2. Insure that it is all there and is serviceable.
B20 - 3. Verification is checking for accuracy. Calibration usually requires adjusting for accuracy.
B20 - 4. Calibration requirements are given in the 33-series TOs.
B20 - 5. AF Form 1297.
B20 - 6. It is used to seal equipment after calibration. Breakage of the seal indicates unserviceable equipment.

B21 - 1. TO 33K1-100.

B21 - 2. There is very little difference between PMEL and shop calibration of test equipment. Equipment requiring special calibration equipment and specially trained people is usually done at PMEL.
B21 - 3. Send a corrected copy of the schedule to PMEL.

B22 - 1. To meet changes in testing or maintenance requirements.
B22 - 2. If you must modify identical test sets, modify one at a time in order to maintain operational capability.

B23 - 1. Actuating a torque wrench through a few release cycles insures that the internal parts are coated with a thin film of lubrication.
B23 - 2. 1/4, 1/2, 3/4, and full range.
B23 - 3. All settings.
B23 - 4. Cap screw from the side of the wrench body.
B23 - 5. The flux in the solder and the high heat required to melt the solder.
B23 - 6. Maintenance Data Collection Equipment Inventory Report 2.

B24 - 1. To measure the size of the cable for which tension is being measured.
B24 - 2. Between the anvils and the plunger.
B24 - 3. To clamp lthe cable in place or release the cable.
B24 - 4. Slide the pointer lock to ON before removing the tensiometer from the cable.
B24 - 5. Counterclockwise.
B24 - 6. Releasing the handle locks the tensiometer on the cable.
B24 - 7. Use the test bar or a tensiometer tester.
B24 - 8. Rotate the indicator rim to zero the tensiometer.

B25 - 1. It combines the functions of an AC and DC voltmeter, an ammeter, and an ohmmeter.
B25 - 2. Once the FUNCTION switch has been set, the correct instrument range to provide an accurate scale indication is set with the RANGE switch.
B25 - 3. Variations due to battery condition, temperature, and range and function settings.
B25 - 4. 10 megohms.
B25 - 5. In parallel.
B25 - 6. The SPECIAL position.
B25 - 7. MA/PULSE MA.
B25 - 8. In series.
B25 - 9. The OHMS STD position.
B25 - 10. To adjust the meter for full-scale deflection (0 ohms).
B25 - 11. By changing the POLARITY switch to DC-.

B26 - 1. It is used to measure RMS voltages from 500 microvolts to 500 volts and to serve as a wideband amplifier.
B26 - 2. (1) Do not measure line voltage or any two phases of three-phase power; (2) observe test lead polarity; and (3) when using a ground buster, put the ME-6D/U on an insulated pad and touch only the insulated parts of the meter.
B26 - 3. With the range selector set at 500, connect the test leads and power cord. After a 2-minute warmup, connect the test leads to the circuit (GND lead first). Decrease the range selector until the reading is between 5 and 5. Reset range to 500 and disconnect leads (INP lead first). Disconnect power cord.

B27 - 1. (1) Conventional AC/DC voltmeter, (2) a differential AC/DC voltmeter, and (3) a megohmmeter.
B27 - 2. a. Shows null ranges as the range control is changed.
    b. Serve as decimal points for the voltage readout windows. Decimal point changes as the range knob is changed.
    c. Provides a readout to let the operator know the position of the AC-DC POLARITY switch.
B27 - 3. a. 1000.
    b. TVM.
    c. + (positive).
    d. Zero.
    e. ON.

B28 - 1. Perform setup operation and connect the meter to the unknown voltage. Determine the approximate value of the unknown voltage. Set the readout dials to this approximate voltage. Rotate NULL switch and for each setting, zero the meter with the readout dials. When the meter is nulled, the value of the voltage can be read off the readout dials.
B28 - 2. Perform setup operation and set the RANGE switch, NULL switch, and the voltage dials according to the range selected. As an example, to measure 900 VAC, set the NULL switch to TVM and the readout dials will have no effect.
B28 - 3. Connect the unknown resistance to the binding posts and set the RANGE switch to 10. Adjust the meter to read out the proper voltage. Substitute the meter and readout dial readings in the proper formula and solve for the unknown resistance.

B29 - 1. To measure DC voltages from 1 millivolt to 1000 volts.
B29 - 2. a. VDC only.
    b. VDC, DC amps, and ohms.
    c. VDC and VAC.
B29 - 3. 115- or 230-volt AC, 50 to 1000 Hz.
B29 - 4. The OVERRANGE light will light and 0.500 will be displayed on the front panel.

B30 - 1. 115 VAC and 230 VAC.
B30 - 2. In the LOW position.

B31 - 1. Unshielded leads, straight coaxial leads, 1:1 probes, and 10 × attenuator probes.
B31 - 2. Short unshielded leads.
B31 - 3. About 1 meghom paralleled by about 20 pf.
B31 - 4. Insert probe into 1 KC CAL connector and obtain 2 or 3 cycles on the display. If the square wave is distorted, unlock the locking sleeve and adjust the sleeve and adjust the probe for a perfect square wave.

B32 - 1. When pressed, returns the display to the screen by reducing horizontal and vertical deflection. Used to locate trace when it exceeds scan of display area.
B32 - 2. The ALT MODE.
B32 - 3. The PME laboratory.

B32 - 4. Provides continuously variable sweep rate to at least 2.5 times setting of A TIME/DIV switch. Sweep rate is calibrated when control is set fully clockwise to CAL.
B32 - 5. The CALIBRATOR on the side panel.
B32 - 6. A .8A slow-blow fuse.
B32 - 7. The UNCAL light next to the VOLTS/DIV switch of the channel you are using.

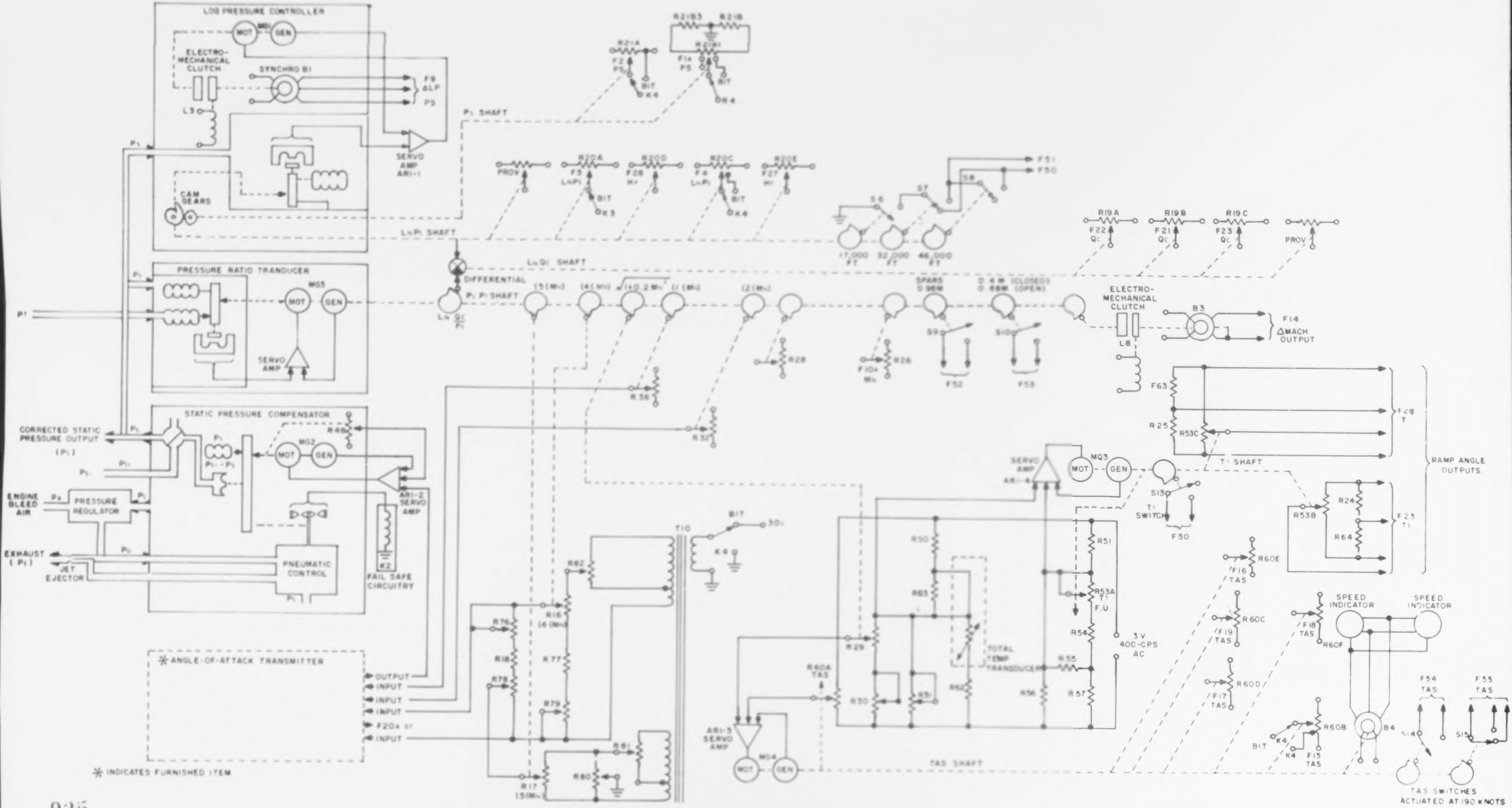
B33 - 1. To DC.
B33 - 2. To obtain the deflection factor selected by the VOLTS/DIV control.
B33 - 3. 5 (divisions) × 2 (VOLTS/DIV) = 10 volts peak to peak. Peak = 10/2 = 5 volts. RMS = .707 × 5 = 3.54 volts.
B33 - 4. 4 (divisions) × (VOLTS/DIV) × 10 (attenuation) = 200 volts. Peak = 100 volts. RMS = .707 × 100 = 70.7 volts.

B34 - 1. About 5 divisions.
B34 - 2. Set the AC GND DC switch to DC, apply the reference DC to the INPUT connector, and position the trace to the reference line.
B34 - 3. The INVERT switch must be pushed in when using Channel 2 to indicate positive polarity above the line and negative polarity below the line.
B34 - 4. Instantaneous = 4.1 × +1 × 2 × 1 = 8.2 VDC.
B34 - 5. Instantaneous = 3.8 × -1 × 5 × 10 = -190 VDC.

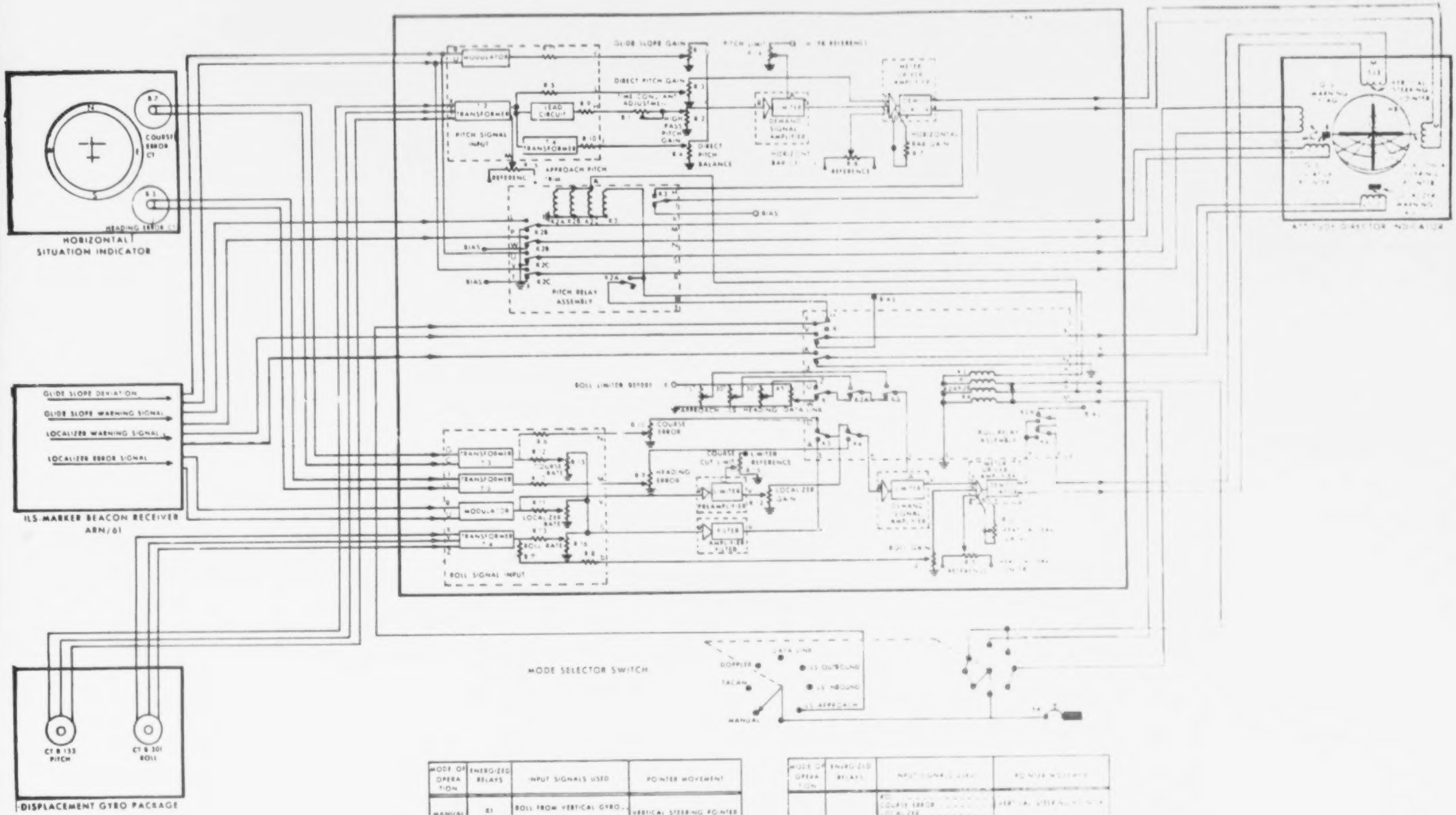
B35 - 1. No. Because only time duration can be measured directly off the scope and then the time duration, using the proper formula, must be converted to frequency.
B35 - 2. It is set to the fastest sweep rate that will display less than 8 divisions between the time measurement points.
B35 - 3. Use the first graticule line as the starting point.
B35 - 4. Frequency $= \dfrac{1}{0.3 \times 10^{-3}} = 3.33$ kHz.
B35 - 5. Time duration $= \dfrac{6.8 \times .2 \text{ msec}}{1}$

$= 1.36$ msec.

Fequency $= \dfrac{1}{1.36 \times 10^{-3}} = 735$ Hz.


LOG PRESSURE CONTROLLER
MOT
GEN
MG1
ELECTRO-MECHANICAL CLUTCH
SYNCHRO B1
F9 ΔLP PS
L3
SERVO AMP AR1-1
CAM GEARS
PS SHAFT
LnPS SHAFT
R21A
F2 PS
BIT
K4
R21B3
R21B
R21B1
F1A PS
PROV
R20A
F3 LnPS
K3
R20D
F28 HP
R20C
F4 LnPS
R20E
F27 HP
S6
S7
S8
F51
F50
17,000 FT
32,000 FT
46,000 FT
R19A
F22 QC
R19B
F21 QC
R19C
F23 QC
PROV
PRESSURE RATIO TRANDUCER
MG5
SERVO AMP
LnQC SHAFT
DIFFERENTIAL
PT PS SHAFT
Ln QC/PS
(.5 MN)
(.4 MN)
(.4+0.2 MN)
(1 MN)
(2 MN)
SPARE 0.96M
0.4 M (CLOSED) 0.88M (OPEN)
S9
S10
F52
F53
ELECTRO-MECHANICAL CLUTCH
B3
L8
F14 ΔMACH OUTPUT
R28
F10A MN
R26
R36
R32
PT
STATIC PRESSURE COMPENSATOR
CORRECTED STATIC PRESSURE OUTPUT (PC)
PS
PT - PS
R48
MG2
AR1-2 SERVO AMP
K2
FAIL SAFE CIRCUITRY
ENGINE BLEED AIR
PRESSURE REGULATOR
PE
PNEUMATIC CONTROL
EXHAUST (PE)
JET EJECTOR
F63
R25
R53C
F28 T
TT SHAFT
RAMP ANGLE OUTPUTS
SERVO AMP AR1-4
MQ3
S13
TT SWITCH
F50
R53B
R24
R64
F23 TT
T10
BIT
30V
K4
R82
R76
R16 (.4 MN)
R18
R77
R78
R79
R81
R80
R17 (.5 MN)
✻ ANGLE-OF-ATTACK TRANSMITTER
OUTPUT
INPUT
INPUT
INPUT
F20A BIT
INPUT
✻ INDICATES FURNISHED ITEM
R50
R83
R29
R51
R53A TT F.U.
R54
R55
R57
R56
R52
R30
R31
TOTAL TEMP TRANSDUCER
3 V 400-CPS AC
R60A TAS
AR1-5 SERVO AMP
MG4
TAS SHAFT
R60E
F16 TAS
R60C
F19 TAS
R60D
F17 TAS
F18 TAS
R60F
SPEED INDICATOR
SPEED INDICATOR
B4
R60B
F15 TAS
F54 TAS
F55 TAS
S14
S15
TAS SWITCHES ACTUATED AT 190 KNOTS

Foldout 1. CADC output diagram.


HORIZONTAL SITUATION INDICATOR
COURSE ERROR CT
HEADING ERROR CT
N
S
E
GLIDE SLOPE DEVIATION
GLIDE SLOPE WARNING SIGNAL
LOCALIZER WARNING SIGNAL
LOCALIZER ERROR SIGNAL
ILS-MARKER BEACON RECEIVER ARN/61
CT B 133 PITCH
CT B 301 ROLL
DISPLACEMENT GYRO PACKAGE
MODULATOR
T 2 TRANSFORMER
PITCH SIGNAL INPUT
LEAD CIRCUIT
T 4 TRANSFORMER
GLIDE SLOPE GAIN
DIRECT PITCH GAIN
TIME CONSTANT ADJUSTMENT
HIGH PASS PITCH GAIN
DIRECT PITCH BALANCE
PITCH LIMIT
REFERENCE
APPROACH PITCH TRIM
DEMAND SIGNAL AMPLIFIER
HORIZONTAL BAR GAIN
METER DRIVE AMPLIFIER
BIAS
K2A
K2B
K2C
K3
PITCH RELAY ASSEMBLY
ROLL LIMITER REFERENCE
APPROACH ILS HEADING DATA LINE
COURSE ERROR
HEADING ERROR
COURSE CUT LIMIT
LIMITER REFERENCE
TRANSFORMER T 3
COURSE RATE
LOCALIZER RATE
ROLL RATE
TRANSFORMER T 4
ROLL SIGNAL INPUT
LIMITER
PREAMPLIFIER
FILTER
AMPLIFIER FILTER
LOCALIZER GAIN
ROLL RELAY ASSEMBLY
ROLL GAIN
ATTITUDE DIRECTOR INDICATOR
MODE SELECTOR SWITCH
DATA LINE
DOPPLER
TACAN
MANUAL
ILS OUTBOUND
ILS INBOUND
ILS APPROACH

MODE OF OPERATION	ENERGIZED RELAYS	INPUT SIGNALS USED	POINTER MOVEMENT
MANUAL	K1 K4	ROLL FROM VERTICAL GYRO HEADING ERROR FROM HSI	VERTICAL STEERING POINTER
TACAN	K1 K4	ROLL . . . . HEADING ERROR	VERTICAL STEERING POINTER
DOPPLER	K1 K4	ROLL . . . . HEADING ERROR	VERTICAL STEERING POINTER
ILS OUTBD	K1 K4	ROLL . . . . HEADING ERROR	VERTICAL STEERING POINTER
DATA LINE	K4	ROLL . . . . HEADING ERROR	VERTICAL STEERING POINTER

MODE OF OPERATION	ENERGIZED RELAYS	INPUT SIGNALS USED	POINTER MOVEMENT
ILS INBD	K2	ROLL . . . . COURSE ERROR . . . . . . LOCALIZER	VERTICAL STEERING POINTER
		GLIDESLOPE DEVIATION . . . GLIDESLOPE FLAG ALARM . . LOCALIZER FLAG ALARM . .	GLIDESLOPE DEVIATION POINTER GLIDESLOPE WARNING FLAG LOCALIZER WARNING FLAG
ILS APPROACH	K2	ROLL . . . . COURSE ERROR . . . . . . LOCALIZER	VERTICAL STEERING POINTER
		GLIDESLOPE DEVIATION . . . GLIDESLOPE FLAG ALARM . . LOCALIZER FLAG ALARM . .	GLIDESLOPE DEVIATION POINTER GLIDESLOPE WARNING FLAG LOCALIZER WARNING FLAG
	K3	PITCH FROM VERTICAL GYRO GLIDESLOPE DEVIATION	HORIZONTAL STEERING POINTER

Foldout 2. Flight director system schematic.

BEST COPY AVAILABLE

S T O P - 1. MATCH ANSWER SHEET TO THIS EXERCISE NUMBER.
2. USE NUMBER 2 PENCIL ONLY.

EXTENSION COURSE INSTITUTE
VOLUME REVIEW EXERCISE

32551 06 21

FLIGHT AND NAVIGATION INSTRUMENTS

Carefully read the following:

DO's:

1. Check the "course," "volume," and "form" numbers from the answer sheet address tab against the "VRE answer sheet identification number" in the righthand column of the shipping list. If numbers do not match, return the answer sheet and the shipping list to ECI immediately with a note of explanation.
2. Note that item numbers on answer sheet are sequential in each column.
3. Use a medium sharp #2 black lead pencil for marking answer sheet .
4. Write the correct answer in the margin at the left of the item. (When you review for the course examination, you can cover your answers with a strip of paper and then check your review answers against your original choices.) After you are sure of your answers, transfer them to the answer sheet. If you have to change an answer on the answer sheet, be sure that the erasure is complete. Use a clean eraser. But try to avoid any erasure on the answer sheet if at all possible.
5. Take action to return entire answer sheet to ECI.
6. Keep Volume Review Exercise booklet for review and reference.
7. If mandatorily enrolled student, process questions or comments through your unit trainer or OJT supervisor. If voluntarily enrolled student, send questions or comments to ECI on ECI Form 17.

DON'Ts:

1. Don't use answer sheets other than one furnished specifically for each review exercise.
2. Don't mark on the answer sheet except to fill in marking blocks. Double marks or excessive markings which overflow marking blocks will register as errors.
3. Don't fold, spindle, staple, tape, or mutilate the answer sheet.
4. Don't use ink or any marking other than a #2 black lead pencil.

NOTE: NUMBERED LEARNING OBJECTIVE REFERENCES ARE USED ON THE VOLUME REVIEW EXERCISE. In parenthesis after each item number on the VRE is the Learning Objective Number where the answer to that item can be located. When answering the items on the VRE, refer to the Learning Objectives indicated by these Numbers. The VRE results will be sent to you on a postcard which will list the actual VRE items you missed. Go to the VRE booklet and locate the Learning Objective Numbers for the items missed. Go to the text and carefully review the areas covered by these references. Review the entire VRE again before you take the closed-book Course Examination.

MULTIPLE CHOICE

Note to Student: Consider all choices carefully and select the best answer to each question.

1. (A01) What is the purpose of the baffle and standpipe in the pitot tube?

   a. To restrict air flow to protect the instruments.
   b. To secure and regulate the heater.
   c. To keep out dirt and water.
   d. To reinforce the lip of the pitot tube.

2. (A02) Which of the following airspeed errors can not be compensated for by a correction card?

   a. Density error.
   b. Instrument error.
   c. Mechanical error.
   d. Installation error.

3. (A03) What are the inputs to the true airspeed indicator?

   a. Pitot pressure, static pressure, and 115 volts, 400 Hz.
   b. Airspeed, altitude, and 26 volts, 400 Hz.
   c. Pitot pressure, static pressure, and temperature.
   d. Airspeed, altitude, and density corrections.

4. (A04) The ratio of movement of the sector and rocking shaft assembly in the maximum-allowable-airspeed indicator caused by an increase in altitude depends on the

   a. existing temperature.
   b. speed of the aircraft.
   c. Mach number set into the mechanism.
   d. setting of the maximum allowable pointer.

5. (A05) What are the two sensing mechanisms of the transonic Machmeter?

   a. Diaphragm and aneroid.
   b. Diaphragm and dual bellows.
   c. Aneroid and temperature bellows.
   d. Diaphragm and temperature bellows.

6. (A06) What inputs to the C-2 computer are used to generate the signal which makes possible the measurement of Mach number and true airspeed?

   a. Cockpit temperature, ram air, and cabin pressure.
   b. Indicated airspeed, air density, and vertical velocity.
   c. Ambient temperature, local pressure, and engine thrust.
   d. Outside temperature and pitot-static system pressures.

7. (A06) What is the function of the synchrotel in the C-2 computer?

a. It operates as a standard synchro.
b. It is the temperature correction mechanism in the computer.
c. It generates the electrical signal that offsets balanced voltages.
d. It is the component that operates the index marker in the indicator.

8. (A07) The relationship between the barometric scale and altimeter pointers depends entirely on the

a. local altitude.
b. aircraft speed.
c. local temperature.
d. standard atmosphere.

9. (A07) To avoid the error between indicated and true altitude at high altitudes, the altimeters of all aircraft flying above 18,000 feet are set at how many inches of mercury?

a. 28.82.
b. 29.92.
c. 30.32.
d. 31.22.

10. (A08) The minimum acceptable range of pointer movement when turning the adjusting screw on a rate-of-climb indicator is from plus

a. 200 feet to minuw 200 feet.
b. 400 feet to minus 400 feet.
c. 600 feet to minus 600 feet.
d. 800 feet to minus 800 feet.

11. (A09) Which of the following is used in an altimeter to reduce temperature error?

a. Metallic spring.
b. Temperature bulb.
c. Temperature bridge.
d. Range compensating fork.

12. (A12) Which of the following provides power for the analog computations in the CPU-46/A computer?

a. An autotransformer.
b. The aircraft AC bus.
c. A three-stage amplifier.
d. Two closed servoloop systems.

13. (A13) Linkages attached to aneroid capsules in the CPU-66/A computer provides displacements which rotate the main rocking shaft as a function of

a. Mach.
b. airspeed.
c. corrected altitude.
d. uncorrected altitude.

14. (A13) The Mach computation cam in the CPU-66/A computer rotates as a function of

a. Mach.	c. true airspeed.
b. altitude.	d. indicated airspeed.

15. (A14) In the primary mode of operation for the AAU-19/A altimeter, a voltage output to the amplifier will be developed when

a. the input voltage is above 50 VAC.
b. the output voltage is below 50 VAC.
c. the indicator and transmitter synchros are aligned.
d. there is a difference between the indicator and transmitter synchros.

16. (A15) Test equipment required to test the AIMS is the

a. TTU-205 and TTU-26/E.	c. TTU-205 and TTU-229/E.
b. TTU-205 and TTU-27/E.	d. TTU-229/E and TTU-26/E.

17. (A16) To perform a complete checkout of the AIMS, what other system must be operated?

a. The airspeed computer system.
b. The IFF transponder, Mode C, system.
c. The inertial navigation system.
d. The automatic flight control system.

18. (A17) If an inflight malfunction indicates that the AIMS altimeter reads high at all altitudes in STBY, what type of check should be made on the altimeter?

a. Scale error check.	c. Position error check.
b. Friction error check.	d. Hysteresis error check.

19. (A18) Any increase in altitude will normally cause the airspeed indicator to read a value

a. higher than true airspeed.
b. lower than true airspeed.
c. the same as true airspeed.
d. that may be lower or higher than true airspeed.

20. (A19) Which type of bellows used in the CADC may contain oil to minimize work hardening and cracking?

a. Evacuated bellows.	c. Aneroid bellows.
b. Filled bellows.	d. Differential bellows.

21. (A20) A pressure that is measured in reference to a complete vacuum is

a. ambient pressure.
b. absolute pressure.
c. differential pressure.
d. direct pressure.

22. (A21) What causes erroneous static pressures to be sensed by the aircraft's static ports?

a. Unobstructed holes in the static ports.
b. Power supply variations.
c. Shock waves and airflow disturbances.
d. Altitude and heading variations.

23. (A22) Total temperature is static temperature plus

a. the rise in temperature caused by compression of the air.
b. the rise in temperature caused by increased altitudes.
c. the constant temperature value at the prevailing altitude.
d. 3.6°F for each 1,000 feet of altitude change.

24. (A23) Which of the following is an input to the log pressure controller (LPC) module of the CADC?

a. True static pressure from the SPC.
b. Total pressure from the pitot tube.
c. Mach number from the Mach sector module.
d. Total temperature from the temperature probe.

25. (A25) Which of the following is not a use of mechanical differentials in air data equipment?

a. Solving problems by addition or subtraction of the logarithms of various functions.
b. Solving multiplication or division problems by adding or subtracting logs using simple differential gearing.
c. Functioning as a corrective device on air data output shafts.
d. Compensating for differences in potential due to unbonded modules.

26. (A27) What are the outputs of the gearbox module?

a. An output voltage proportional to Ps, LnPs, Qc and $\triangle$ Mach.
b. An output voltage proportional to LnPs, Ps and Qc and a synchro output for $\triangle$ Mach, and a gear rotation to Ps/Pt.
c. An output voltage proportional to $\triangle$ Mach and Ps/Pt and corrected pneumatic outputs.
d. An output voltage proportional to Mn, Tt, Ps, and Qc and a gear rotation for Pr and Ps/Pt and a synchro output for LnQc.

27. (A29) In what form are the outputs of the total temperature servo of the TAS and Tt module?

a. Gear rotations and synchro signals.
b. Mechanical movement.
c. Corrected pneumatic pressures.
d. Voltage ratios and switch actions.

28. (A30) What is the purpose of the jackscrew gears in the static pressure sensor and the pressure ratio sensor?

a. To produce the output of the sensors.
b. To rotate the rotors of synchros.
c. To reposition the sensor fulcum.
d. To keep the beam unbalanced to maintain a signal.

29. (A31) What causes the LPC motor to stop running after a change in static pressure is sensed?

a. A feedback voltage will null the servoloop.
b. A jackscrew will reposition the beam fulcrum.
c. A mechanical linkage will reposition the beam.
d. The SPC will produce an equalizing pressure.

30. (A31) In the LPC of the air data computer, what sensor determines the phasing of the control phase of the LPC servomotor?

a. A phase-correcting network.
b. A coupling transformer.
c. An E-core transformer.
d. A sensor jackscrew.

31. (A32) In the CADC system, when the altitude mode is locked in, any change from this reference altitude is provided by the

a. LPC.
b. PRT.
c. SPC.
d. gearbox module.

32. (A33) In the LPC of the air data computer, what prevents servoloop instability and overshooting?

a. A potentiometer provides a decreasing nulling voltage.
b. A jackscrew repositions the beam fulcrum.
c. A hairspring provides preload tension.
d. A tachometer winding provides negative feedback.

33. (A34) In the (SPC) static pressure compensator of the air data computer, what actuates the poppets of the two pneumatic control valves?

a. Beam movement.
b. Over pressure.
c. Diaphragm expansion.
d. Jackscrew rotation.

34. (A35) The two failure sensing devices in the SPC are the fail-safe

a. relief valve and limit switches.
b. solenoid valve and fail-safe relay.
c. solenoid valve and fulcrum.
d. relay and limit switches.

35. (A36) What prevents the TAS and Tt servosystems from running away when the temperature probe is removed?

a. A switch.
b. A loss of power.
c. A resistor.
d. A capacitor.

36. (A37) What is used in the impact pressure (Qc) mechanization module to remove gear backlash errors?

a. A spring load is attached to the input gear.
b. A spring load is attached to the output gear.
c. A filter is used in the electrical output.
d. A regulator is used on the pressure inputs.

37. (A39) Primary operating power required for CAD computer operation includes 115 VAC,

a. 400 Hz, three-phase, 28 VDC, and 26 VAC, 400 Hz.
b. 60 Hz, three-phase, 28 VDC, and 26 VAC, 400 Hz, single-phase.
c. 400 Hz, three-phase, and 26 VAC, 400 Hz, single-phase.
d. 400 Hz, three-phase, and 28 VDC.

38. (A41) An output from the TAS section is supplied to the

a. navigation computer.
b. autopilot system.
c. flight director system.
d. engine throttle controls.

39. (A43) LnPs outputs are supplied to the

a. altitude and the airspeed computer.
b. airspeed and the navigational computer.
c. the altitude and the navigational computer.
d. the airspeed and the autopilot computer.

40. (A44) A $\triangle$ LnPs output is used for

a. altitude hold.
b. rudder feel.
c. stabilator control.
d. Mach hold.

41. (A46) The first thing to check for when troubleshooting the CADC system is

a. correct input voltages.
b. correct output voltages.
c. pitot-static leaks.
d. the accuracy of indicators.

42. (A46) What type of check do you perform if you check for bent or broken pins, a continuous circuit between specified pins, proper shielding, and shorts to ground or between wires during troubleshooting of an air data computer system?

a. Reliability check.
b. Functional check.
c. Schematic check.
d. Continuity check.

43. (A49) Because of the gyroscopic principle of precession, when a weight is placed on the gimbal to exert a downward pressure, the reaction of the force is

a. 180° away from the applied force in the direction of rotor rotation.
b. 45° away from the applied force in the opposite direction of rotor rotation.
c. 90° away from the applied force in the direction of rotor rotation.
d. 90° away from the applied force in the opposite direction of rotor rotation.

44. (A49) What is used to keep a gyro's spin axis in a definite relationship to the earth's surface?

a. Balance pots.
b. Erection systems.
c. Latitude correction circuits.
d. Additional gimbals.

45. (A50) What is the power requirement for a directional gyro?

a. 28-volt, 400-Hz, 3-phase power.
b. 26-volt, 400-Hz, 3-phase power.
c. 115-volt, 400-Hz, 1-phase power.
d. 115-volt, 400-Hz, 3-phase power.

46. (A52) What causes the directional gyro erection torquer to reverse direction?

a. Reversing the polarity of the applied voltage.
b. Reversing the phasing of the applied voltage.
c. Energizing the windings of the low-inertia motor.
d. Energizing the third winding of the torquer motor.

47. (A53) What indicates that the required 3-phase power, with the proper phase sequence, is applied to the directional gyro?

a. The gyro spins.
b. There is an indication on the voltmeter.
c. The OFF flag disappears from view.
d. The power-on light illuminates.

48. (A54) When you tilt the directional gyro a prescribed amount, turn it to a prescribed indication, let it run for 15 minutes and check to see how far it has precessed, you are checking the indicator for

a. drift.
b. rigidity.
c. power consumption.
d. balance.

49. (A55) In the self-contained electric driven attitude indicator, the gyroscope is mounted with the spin axis

a. parallel to the earth's surface.
b. perpendicular to the earth's surface.
c. perpendicular to the aircraft's vertical axis.
d. parallel to the aircraft's longitudinal axis.

50. (A56) Slight roll position errors during the installation of a new attitude director indicator can be removed by

a. shimming the indicator.
b. adjusting the knob on the front of the indicator.
c. adjusting a potentiometer on the amplifier.
d. adjusting a screw on the displacement gyro.

51. (A57) Bank control information is provided to the pilot by using electrical signals from the

a. rate switching gyroscope.
b. rate-of-turn gyroscope.
c. vertical accelerometer.
d. inclinometer.

52. (A58) The displacement gyro packages senses aircraft movement about which axes?

a. Roll.
b. Pitch.
c. Roll and pitch.
d. Roll, pitch, and yaw.

53. (A59) In the displacement gyro package, the outer roll gimbal is maintained in what relative position?

a. Level with the earth's surface.
b. Level with the aircraft wings.
c. Perpendicular to the earth's surface.
d. Perpendicular to the aircraft's longitudinal axis.

54. (A60) During an immelmann turn, how is the inner roll gimbal affected as the pitch angle is increased beyond 75°?

   a. It becomes less sensitive to roll and more sensitive to aircraft yaw.
   b. It becomes less sensitive to roll and more sensitive to aircraft pitch.
   c. It becomes less sensitive to aircraft yaw and extremely sensitive to pitch.
   d. It becomes less sensitive to pitch and more sensitive to centrifugal force.

55. (A60) As the aircraft rolls out of an immelmann turn, the output signals of the stators in the displacement gyro package are changed by

   a. 90°.
   b. 120°.
   c. 180°.
   d. 270°.

56. (A61) What is the purpose of the bridge rectifiers in the amplifier used in the all-attitude reference system?

   a. Convert AC to DC to operate the solenoids of the relays.
   b. Convert DC to AC to operate the pitch and roll torque motors.
   c. Convert AC to DC to operate the heating elements of the relays.
   d. Convert DC to AC to operate the electrolytic switches.

57. (A61) In the displacement gyro package, why is the roll erection circuit disabled for the first 12 seconds of system operation?

   a. To provide starting torque for the gyro.
   b. To prevent overspeeding of the gyro.
   c. To allow the timing cycle to reset.
   d. To prevent gimbal lock.

58. (A62) In the all-attitude reference system, the function of the compass transmitter is to

   a. establish an azimuth reference.
   b. keep the directional gyro aligned in the DG mode.
   c. sense a true north heading in the slaving mode.
   d. control the outer roll gimbal and prevent a gimbal lock of the directional gyro.

59. (A63) In the compass adapter, the DC voltage applied to the slew motor is for

   a. energizing the fixed phase of the motor.
   b. the operation of the DC operated motor.
   c. locking the slew motor to prevent coasting.
   d. energizing the magnetic clutch to prevent rotation of the mechanical shaft.

60. (A64) What happens when the position of the hemisphere selector switch is changed?

- a. The control phase and the fixed phase voltages for the gyro are reversed.
- b. The operation of the slaving torque motor is reversed.
- c. The slaving torquer precesses the gyro to a predetermined position.
- d. A circuit for synchronization is either opened or closed.

61. (A66) The switching rate gyro eliminates errors caused by the compass

- a. controller and roll erection switch.
- b. transmitter and roll erection switch.
- c. adapter and pitch erection switch.
- d. transmitter and slaving cutout switch.

62. (A67) In the DG mode of operation, if there is an error between the readout on the HSI and the actual aircraft magnetic heading, how is the error corrected?

- a. The pilot corrects for the error by using the set heading adjustment.
- b. The slaving torque motor automatically applies a torque to the DG to counteract total drift.
- c. The latitude compensator automatically corrects it at the rate of 2° per minute.
- d. The polyplane compressor senses and compensates for the error.

63. (A68) In the attitude director system, the signal that controls the position of the outer roll gimbal at extreme pitch attitudes is the signal from the

- a. pitch limit switches.
- b. rate switching gyro.
- c. pitch summing amplifier.
- d. roll summing amplifier.

64. (A70) In troubleshooting the attitude reference systems, what type of component maintenance are you permitted to perform?

- a. Continuity and voltage checks.
- b. Tear down inspections.
- c. Replacement of modules only.
- d. Repairs as necessary.

65. (A72) The TACAN mode of navigation is used as

- a. a long range navigational aid.
- b. a short range navigational aid.
- c. an intercept mission aid only.
- d. a water navigational aid only.

66. (A73) In which mode of the flight director system is pitch and glide slope information used?

a. Manual. c. Doppler.
b. Data link. d. ILS.

67. (A74) Describe the operation of the flight director system, in the ILS inbound mode

a. Pitch, TACAN, and heading error signals deflect the pitch steering pointer which gives a deviation indication.
b. Roll, localizer, or course error signals deflect the vertical steering pointer which give a fly-to indication.
c. Localizer and roll error signals are routed through the roll channel to deflect the horizontal pointer for a fly-to indication.
d. Roll rate, localizer rate, and course rate is used to determine the cross wind correction factor.

68. (A75) Which component of the horizontal situation indicator (HSI) indicates the position of the aircraft in relation to the selected TACAN radial?

a. Course arrow. c. Deviation bar.
b. Heading marker. d. Bearing pointer.

69. (A76) In the manual, data link, or Doppler modes of operation, a transformer in the HSI amplifier is energized to supply the operating voltage for the

a. compass and command attitude amplifiers.
b. bearing and distance amplifiers.
c. command course amplifier and the fixed-phase windings of a servomotor.
d. aircraft bus, course readout, and mode lights.

70. (A77) Compass readings on the HSI are read from the

a. course arrow. c. bearing pointer.
b. lubber line. d. deviation bar.

71. (A78) The jacks on the FDC are provided for making

a. adjustments of the FDC.
b. it adaptable to different type aircraft.
c. continuity checks of the FDC.
d. it adaptable to operate two indicators.

72. (A79) On the attitude director indicator, the localizer warning flag is activated when the

a. horizontal pointer current fails.
b. vertical steering pointer is in error.
c. glide slope signal is lost.
d. vertical steering pointer current fails.

73. (A80) Relay K1 in the FDC permits what reference signal to be mixed with the heading error signal?

a. 30° roll limit.
b. 90° pitch limit.
c. Demand signal.
d. Stable heading.

74. (A81) Refer to F02. What relay in the FDC is energized in the data link mode?

a. K1.
b. K2.
c. K3.
d. K4.

75. (A82) What are the input signals to the FDC in ILS INBOUND mode?

a. Roll, heading set, and ground speed.
b. Pitch, DME, roll limit and glide slope.
c. Compass deviation, latitude correction and roll limit.
d. Roll, course error and localizer.

76. (A83) What signal(s) used in the ILS inbound mode of the flight director system is (are) cut out when ILS approach is selected?

a. Roll error.
b. Course error.
c. Roll and course error.
d. Roll error and localizer.

77. (A84) When the mode selector is placed in the MANUAL position during an operational check of the flight director system, what displays should be moved to the top lubber line?

a. The heading marker and the bearing pointer.
b. The heading marker and the course arrow.
c. The course arrow and the bearing pointer.
d. The azimuth card and the heading marker.

78. (A84) In an operational check of the FDC, when you place the mode selector switch in the DATA LINK mode, what display should move to the target intercept heading?

a. The azimuth dial.
b. The bearing pointer.
c. The course arrow.
d. The heading marker.

79. (A85) Refer to table 3-1. If a pilot's writeup states that the course readout does not agree with the compass card reading when in the MANUAL mode, the most probable cause is

a. a defective ADI.
b. a defective HSI.
c. that relay K2B in the FDC did not energize.
d. that an open wire exists between the course error CT and the FDC.

80. (A86) Bench check procedures for a flight director computer are determined by the

a. part number on the computer.
b. type of suspected malfunction.
c. type of test equipment available.
d. type of aircraft the computer is used on.

81. (A86) What test set is used to bench check a flight director computer?

a. TTU-229.
b. 476E-1.
c. 586E-4.
d. LT3454.

82. (A88) The transistorized electronic choppers in the MSSA auxiliary amplifier are used to

a. change the mechanical movement to an electrical signal.
b. change 400-Hz AC to DC.
c. convert a DC signal from data link to a 400-Hz AC signal.
d. convert an electrical signal to mechanical movement.

83. (A88) Fine and coarse Mach and IAS signals in the MSSA amplifier are controlled by

a. switching diodes.
b. a rate generator.
c. limiting potentiometer.
d. the command relay coil.

84. (A89) In the servomagnetic amplifiers, coupling between the AC excitation applied to the primary winding of each magnetic amplifier section and the series connected secondary windings are controlled by the

a. direction of each DC current.
b. magnitude of each DC current.
c. direction of each AC current.
d. magnitude of each AC current.

85. (A90) Flight information is obtained from four moving tape presentations in the MSSA indicator which show Mach,

a. angle of attack, g, and indicated airspeed.
b. minimum safe speed, true altitude, and indicated airspeed.
c. g-units, altitude, and Qc.
d. altitude, vertical speed, and minimum safe speed.

86. (A91) In the MSS system, a fine readout of g-forces on the aircraft is provided by the

a. moving tape.
b. moving scale.
c. lubber line.
d. digital counter.

87. (A92) The Mach section of the MSSA indicator displays

a. Mach, command Mach, and airspeed.
b. maximum safe Mach and airspeed.
c. command Mach, maximum safe Mach, and Mach.
d. minimum safe speed and minimum safe Mach.

88. (A93) When does the command IAS counter give a digital readout of the actual indicated airspeed?

a. Never. It displays command information only.
b. When DATA LINK mode is selected.
c. When MANUAL MODE is selected.
d. When the slew switch is in DETENT position.

89. (A95) The quadrature rejection circuit in the AVS auxiliary amplifiers removes the quadrature voltages that are

a. 90° out of phase with the signal voltage.
b. 90° out of phase with the line voltage.
c. 180° out of phase with the signal voltage.
d. 180° out of phase with the line voltage.

90. (A96) How is the vertical-speed indication affected when the marker reaches the extremities of the fixed scale?

a. The vertical-speed indication must be read from the readout window.
b. The marker returns to zero and vertical speed is read on the MSSA.
c. The marker is disengaged and vertical speed is obtained from the vertical tape.
d. The marker reverses direction and vertical speed is read on the opposite side of the scale.

91. (A97) The range of the sensitive altitude tape is

a. 0 to 80,000 feet.
b. 0 to 50,000 feet.
c. -1,000 to 50,000 feet.
d. -1,000 to 80,000 feet.

92. (A98) The aneroid barometer in the AVS indicator senses

a. aircraft altitude.
b. command altitude.
c. cabin pressure altitude.
d. target altitude.

93. (A99) An operational check of the airspeed and altitude tapes can be performed by using a

a. pitot-static tester.
b. synchro tester.
c. pressure and vacuum source.
d. computer test set.

94. (B01) If the command Mach marker works normally in the manual position, which components does this indicate are working properly?

a. The command Mach amplifier, servomotor, and mechanical linkage.
b. The command Mach amplifier, the DATA LINK data source, and mechanical linkage.
c. Relay K1 or K2, the command data source, and the mechanical linkage.
d. The servomotor, connecting wiring, mode selector switch, and the electronic chopper.

95. (B02) If an aircraft is flying north at 250 knots and has a 50-knot tail wind, from which direction will the relative wind appear to come?

a. North.
b. South.
c. East.
d. West.

96. (B03) What positions the angle of attack/stall warning sensing element to develop a signal?

a. Pitot pressure against its diaphragm.
b. Relative wind around its vane.
c. Directional position of the aircraft's weapons.
d. Ambient air around the static ports.

97. (B04) Which component of the angle of attack/stall warning system houses the stall warning test circuit?

a. Computer unit.
b. Flap transmitter.
c. Wing mounted AoA transmitter.
d. Test panel assembly.

98. (B05) In the AoA/SW system, indication of an impending stall is indicated by the column shaking which is caused by a

a. vibrating reed. c. vibrating transformer.
b. rotating circular weight. d. rotating transformer.

99. (B08) You can check the wing mounted AoA transmitter on the aircraft by measuring

a. voltages at the computer.
b. voltages at the indicator.
c. resistances at the computer.
d. resistances at the indicator.

100. (B09) In the reflection of light, the angle of incidence equals the

a. normal. c. angle of refraction.
b. perpendicular. d. angle of reflection.

101. (B11) Lenses are primarily used to refract light rays and prisms are used to

a. bend light rays. c. block light rays.
b. converge light rays. d. filter light rays.

102. (B12) The sextant is used to measure

a. refraction of light.
b. angular distance between objects on the ground.
c. distance of the aircraft to objects on the ground.
d. celestial altitudes.

103. (B14) Which part of the sextant interprets the action of a moving ball across a rotating disc?

a. The telescope tube. c. The sextant body.
b. The bubble assembly. d. The averager.

104. (B15) When moisture is present in the sextant telescope tube, the silica turns

a. pink. c. green.
b. blue. d. yellow.

105. (B16) What controls the amount of sunlight entering the bubble unit of a sextant?

a. The shutter assembly. c. The index prism.
b. The diffuser. d. The eyepiece.

106. (B17) Viewed through the sextant eyepiece, true heading is read from the

a. azimuth counter.	c. azimuth scale.
b. altitude scale.	d. altitude counter.

107. (B18) The collimator is used to check a sextant for

a. azimuth error.	c. bubble leakage.
b. index error.	d. mount aggreement.

108. (B19) When checking alignment, the mount azimuth scale should agree with the azimuth counter within plus or minus

a. 0.10°.	c. 1.10°.
b. 1.00°.	d. 1.25°.

109. (B21) What TO gives the authorized calibration intervals for each piece of Air Force test equipment?

a. TO-31-1-141.	c. TO-33D7-3-60-14.
b. TO-32B1-14-101.	d. TO-33K-1-100.

110. (B22) If a test set is modified, how is it normally distinguished from others that are not modified?

a. It is painted a different color.
b. The type number is changed.
c. A dash number is added to the part number.
d. The modification data is stenciled on the case of the tester.

111. (B23) How do you lubricate the internal parts of a torque wrench before you check it?

a. Hold it upside down for 2 minutes.
b. Add grease to the ball bearings.
c. Operate it through a few release cycles.
d. Apply a few drops of oil through the oil hole.

112. (B24) How do you obtain accurate readings when using the test bar provided with the C-8 tensiometer?

a. Insert the test bar with the flanges down.
b. Zero the indicator rim for 1/16-inch cable.
c. Know each reading should be within 1 percent of the value indicated on the bar.
d. Set the cable size indicator for 3/8-inch cable.

113. (B25) What are the input impedances of the AN/PSM-37 multimeter?

a. 1000 ohms/volt, 20,000 ohms/volt, and a fixed 10 megohms.
b. 1000 ohms/volt, 20,000 ohms/volt, and 10 megohms/volt.
c. 10,000 ohms/volt, 20,000 ohms/volt, and a fixed 10 megohms.
d. 10,000 ohms/volt, 20,000 ohms/volt, and a 10 megohms/volt.

114. (B25) The shunt MX-9127/PSM-37 increases the current range to a maximum fullscale value of

a. 1 amp.
b. 2 amps.
c. 5 amps.
d. 10 amps.

115. (B26) What type of meter scale does the electronic multimeter ME-6D/U use?

a. Linear.
b. Micrometer.
c. Differential.
d. Logarithmic.

116. (B27) When used as a differential voltmeter, the 873A operates on the

a. inductive bridge principle.
b. potentiometer principle.
c. AC to DC conversion theory.
d. conventional detection theory.

117. (B29) Which of the following plug-in units is used to increase the capability of the Model 3440A Digital Voltmeter so it can be used as an ohmmeter and ammeter?

a. Model 3441A Range Selector.
b. Model 3444A Multifunction Unit.
c. Model 3442A Automatic Range Selector.
d. Model 3443A High Gain/Auto Range Unit.

118. (B30) If your 230-volt line measures 270 volts, which switch on the Type 453 oscilloscope compensates for this high line voltage?

a. CAL.
b. LEVEL.
c. VOLTS/DIV.
d. HIGH-LOW.

119. (B31) Which oscilloscope probe offers the least circuit loading?

a. 1:1 probe.
b. Unshielded leads.
c. 10 X attenuator probe.
d. Straight coaxial leads.

120. (B32) Which of the following is not a position of the COUPLING switch on the 453 Oscilloscope?

a. AC.
b. DC.
c. AUTO.
d. LF REJ.

121. (B32) What switch on the 453 Oscilloscope selects the amplitude point on the triggering signal where sweep is triggered?

a. LEVEL.
b. SLOPE.
c. HF STAB.
d. A AND B TIME/DIV AND DELAY TIME.

122. (B33) If a peak-to-peak sine wave on the 453 Oscilloscope has a vertical deflection of 4.8 divisions with a VOLTS/DIV setting of .2, what is the value of the peak value?

a. 0.48 volts.
b. 0.96 volts.
c. 4.80 volts.
d. 9.60 volts.

123. (B34) What is the value of an instantaneous DC voltage whose vertical distance is 3.8 divisions below the reference line if you use a 10X attenuator probe and a VOLTS/DIV setting of .5?

a. +17.5 volts.
b. 19.0 volts.
c. +1.98 volts.
d. -18.4 volts.

124. (B35) If you were checking a 100 kHz signal on the oscilloscope, how long would you expect the time duration to be?

a. 100 milliseconds.
b. 100 microseconds.
c. 10 milliseconds.
d. 10 microseconds.

END OF EXERCISE

ATC/ECI SURVEY

The remaining questions (125-135) are not part of the Volume Review Exercise (VRE). These questions are a voluntary ATC/ECI survey. Using a number 2 pencil, indicate what you consider to be the appropriate response to each survey question on your answer sheet (ECI Form 35), beginning with answer number 125. Do not respond to questions that do not apply to you. Your cooperation in completing this survey is greatly appreciated by ATC and ECI. (AUSCN 100)

PRIVACY ACT STATEMENT

A. Authority: 5 U.S.C. 301, Departmental Regulations

B. Principal Purpose: To gather preliminary data evaluating the ATC/ECI Career Development Course (CDC) Program.

C. Routine Uses: Determine the requirement for comprehensive evaluations in support of CDC program improvement.

D. Whether Disclosure is Mandatory or Voluntary: Participation in this survey is entirely voluntary.

E. Effect on the Individual of not Providing Information: No adverse action will be taken against any individual who elects not to participate in any or all parts of this survey.

QUESTIONS:

125. If you have contacted ECI for any reason during your enrollment, how would you describe the service provided to you?

a. Excellent.
b. Satisfactory.
c. Unsatisfactory.
d. Did not contact ECI.

126. My ECI course materials were received within a reasonable period of time.

a. Strongly agree.
b. Agree.
c. Disagree.
d. Strongly disagree.

127. The condition of the course materials I received from ECI was:

a. A complete set of well-packaged materials.
b. An incomplete set of well-packaged materials.
c. A complete set of poorly packaged materials.
d. An incomplete set of poorly packaged materials.

128. The reading level of the material in the course was too difficult for me.

a. Strongly agree.
b. Agree.
c. Disagree.
d. Strongly disagree.

129. The technical material in the course was too difficult for me at my present level of training.

a. Strongly agree.
b. Agree.
c. Disagree.
d. Strongly disagree.

130. The illustrations in the course helped clarify the information for me.

a. Strongly agree.
b. Agree.
c. Disagree.
d. Strongly disagree.

131. Approximately how much information in the course provides general information about your AFSC?

a. Between 80 and 99%.
b. Between 60 and 79%.
c. Between 40 and 59%.
d. Between 20 and 39%.

132. Approximately how much information in the course was current?

a. Between 80 and 99%.
b. Between 60 and 79%.
c. Between 40 and 59%.
d. Between 20 and 39%.

133. The format of the text (objective followed by narrative and exercises) helped me study.

a. Strongly agree.
b. Agree.
c. Disagree.
d. Strongly disagree.

134. The volume review exercise(s) helped me review information in the course.

a. Strongly agree.
b. Agree.
c. Disagree.
d. Strongly disagree.

135. Check the rating which most nearly describes the usefulness of the information in this CDC in your upgrade training program.

a. Excellent.
b. Satisfactory.
c. Marginal.
d. Unsatisfactory.

NOTE: If you know this CDC contains outdated information or does not provide the knowledge that the current specialty training standard requires you to have for upgrade training, contact your OJT advisor and fill out an AF Form 1284, Training Quality Report.

MAIL TO: ECI, GUNTER AFS AL 36118-5643

STUDENT REQUEST FOR ASSISTANCE

PRIVACY ACT STATEMENT

AUTHORITY: 10 USC 8012. PRINCIPAL PURPOSE: To provide student assistance as requested by individual students. ROUTINE USES: This form is shipped with ECI course package, and used by the student, as needed, to place an inquiry with ECI. DISCLOSURE: Voluntary. The information requested on this form is needed for expeditious handling of the student's inquiry. Failure to provide all information would result in slower action or inability to provide assistance to the student.

I CORRECTED OR LATEST ENROLLMENT DATA

1. THIS REQUEST CONCERNS COURSE (1-6)
2. TODAY'S DATE
3. ENROLLMENT DATE
4. AUTOVON NUMBER
5. SOCIAL SECURITY NUMBER (7-15) ☐☐☐ – ☐☐ – ☐☐☐☐
6. GRADE/RANK
7. NAME (First initial, second initial, last name) (17) – (18) – (19-32)
8. ADDRESS (33-53) (54-75)
   OJT ENROLLEES: Address of unit training office with zip code.
   ALL OTHERS: Current mailing address with zip code.
9. NAME OF BASE OR INSTALLATION IF NOT SHOWN ABOVE
10. TEST CONTROL OFFICE ZIP CODE/SHRED (33-38)

II REQUEST FOR MATERIALS, RECORDS, OR SERVICE

Place an 'X' through number in box to left of service requested

X	
1	Request address change as indicated in Section I, Block 8.
2	Request Test Control Office change as indicated in Section I, Block 10.
3	Request name change/correction. *(Provide Old or Incorrect data here)*
4	Request Grade/Rank change/correction.
5	Correct SSAN. *(List incorrect SSAN here.)* *(Correct SSAN should be shown in Section I.)*
6	Extend course completion date. *(Justify in "Remarks")*
7	Request enrollment cancellation. *(Justify in "Remarks")*
8	Send VRE answer sheets for Vol(s): 1 2 3 4 5 6 7 8 9 10 Originals were: [ ] Not received [ ] Lost [ ] Misused
9	Send course materials. *(Specify in "Remarks")* [ ] Not received [ ] Lost [ ] Damaged
10	Course exam not yet received. Final VRE submitted for grading on ______ (date).
11	Results for VRE Vol(s) 1 2 3 4 5 6 7 8 9 10 not yet received. Answer sheet(s) submitted ______ (date).
12	Results for CE not yet received. Answer sheet submitted to ECI on ______ (date).
13	Previous inquiry ([ ] ECI Fm 17, [ ] ltr, [ ] msg) sent to ECI on ______ (date).
14	Give instructional assistance as requested on reverse.
15	Other *(Explain fully in "Remarks")*

FOR ECI USE ONLY

14 G	33	
K	VOL 33-35	CH 36-38
M	33-38	39-42
N	33-35	
P	VOL 33-35	
	TC 36-37	38
	DOE 39-43	
Q	33-34 ØØ	35 1
	MC 39-42	

REMARKS *(Continue on reverse)*

OJT STUDENTS must have their OJT Administrator certify this record.

ALL OTHER STUDENTS may certify their own requests.

I certify that the information on this form is accurate and that this request cannot be answered at this station.

SIGNATURE

ECI FORM 17 DEC 84 PREVIOUS EDITION WILL BE USED.

BEST COPY AVAILABLE

REQUEST FOR INSTRUCTOR ASSISTANCE

NOTE: Questions or comments relating to the accuracy or currency of subject matter should be forwarded directly to preparing agency. For an immediate response to these questions, call or write the course author directly, using the AUTOVON number or address in the preface of each volume. All other inquiries concerning the course should be forwarded to ECI.

VRE ITEM QUESTIONED:

COURSE NO ________

VOLUME NO ________

VRE FORM NO ________

VRE ITEM NO ________

ANSWER YOU CHOSE ________ (Letter)

HAS VRE ANSWER SHEET BEEN SUBMITTED FOR GRADING?

☐ YES ☐ NO

REFERENCE

(Textual reference for the answer I chose can be found as shown below.)

IN VOLUME NO ________

ON PAGE NO ________

IN ☐ LEFT ☐ RIGHT COLUMN

LINES ________ THROUGH ________

MY QUESTION IS:

REMARKS

ADDITIONAL FORMS 17 available from trainers, OJT and Education Offices, and ECI. Course workbooks have a Form 17 printed on the last page.

ECI FORM 17, DEC 86 (Reverse)